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**Takuma**

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(54) **SWITCH DEVICE**

(71) Applicant: **Rohm Co., Ltd.**, Kyoto (JP)

(72) Inventor: **Toru Takuma**, Kyoto (JP)

(73) Assignee: **Rohm Co., Ltd.**, Kyoto (JP)

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**B60R 16/03** (2006.01)

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*Primary Examiner* — Jared Fureman

*Assistant Examiner* — Lucy M Thomas

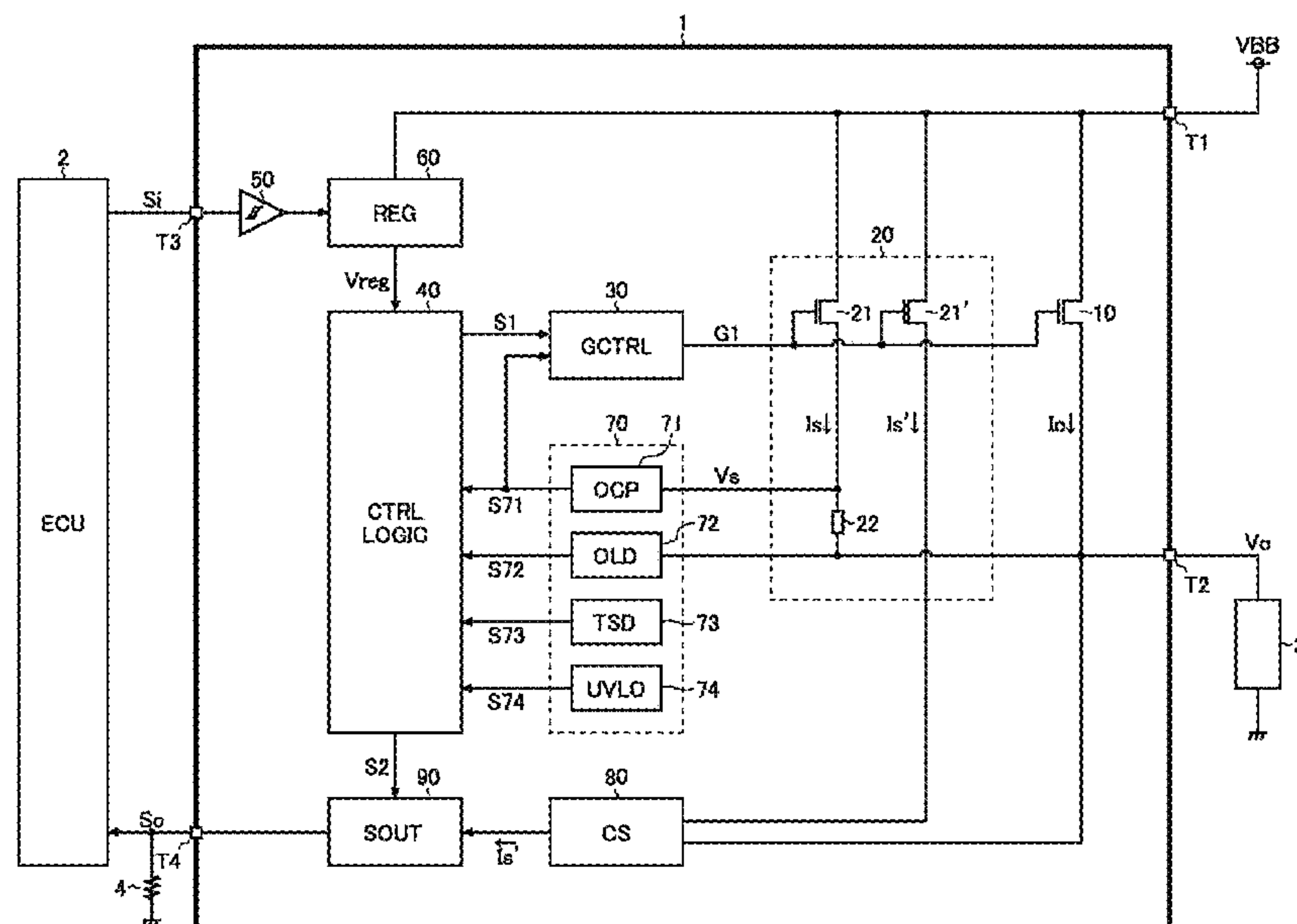
(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57)

**ABSTRACT**

An example switch device includes a switching element to connect/disconnect a current path from a power supply terminal to a ground terminal via a load, and an overcurrent protection circuit to limit output current flowing in the switching element to be an overcurrent limit value or less. When an output short circuit of the load is detected, the overcurrent protection circuit decreases the overcurrent limit value to be lower as a power supply voltage is higher. The overcurrent protection circuit includes a reference current generation portion that includes: a differential amplifier portion, an upper side current generation portion arranged to generate a predetermined an upper side current, a lower side current generation portion arranged to generate a lower side current, and a difference current generation portion arranged to output a difference current based on the lower side current and the upper side current, as the reference current.

**11 Claims, 20 Drawing Sheets**



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(58)	Field of Classification Search		JP	2016-208762 12/2016
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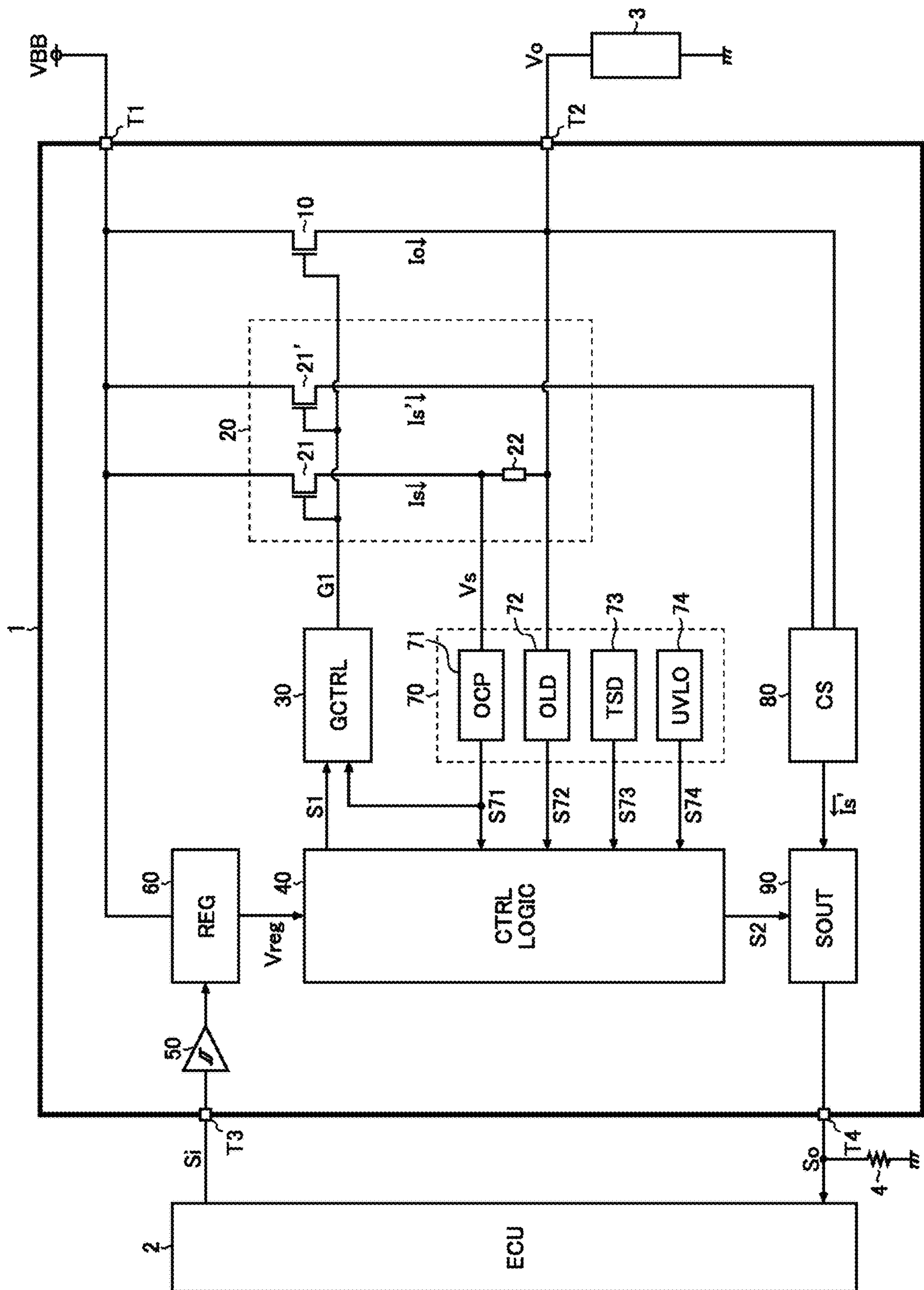


FIG. 2

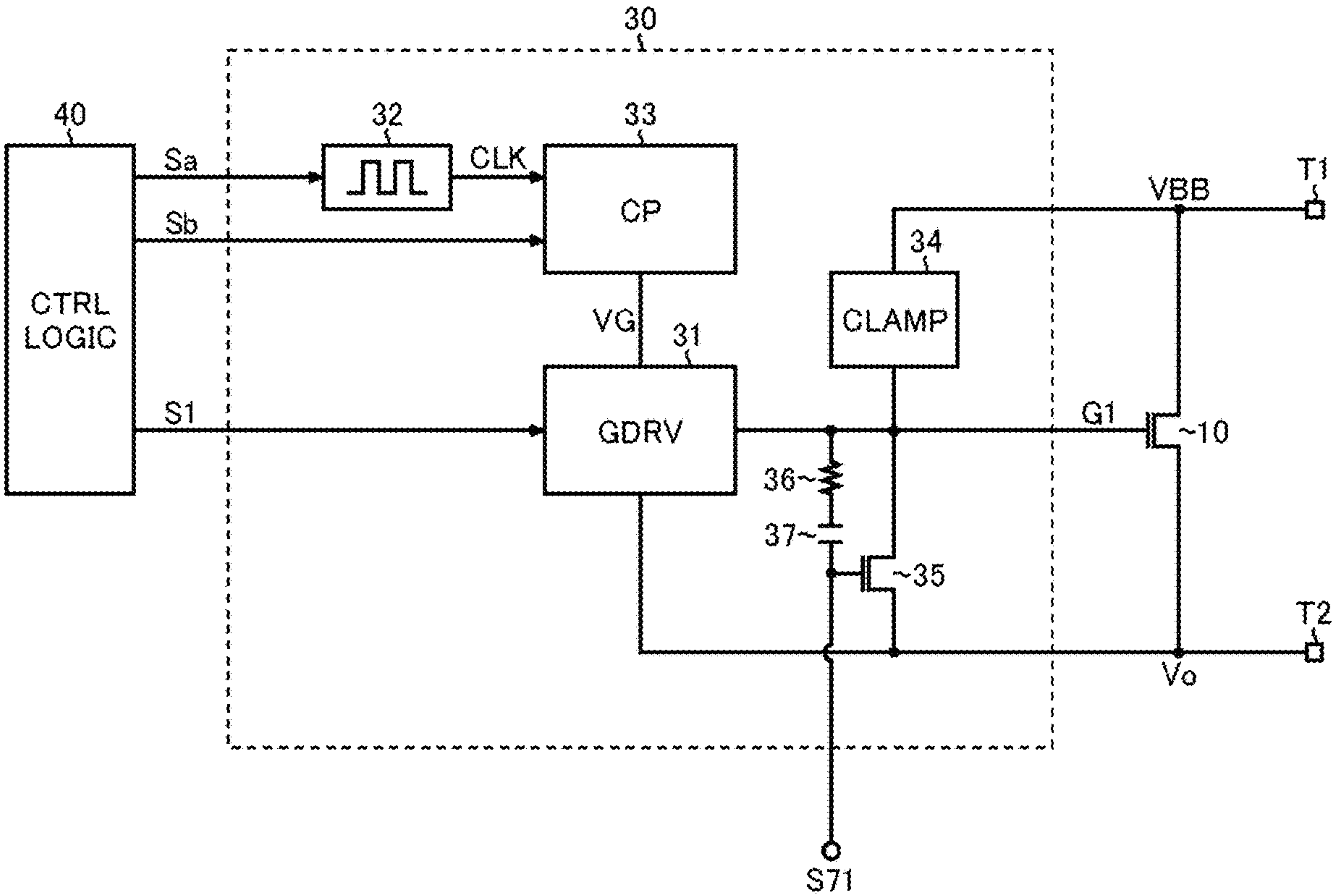
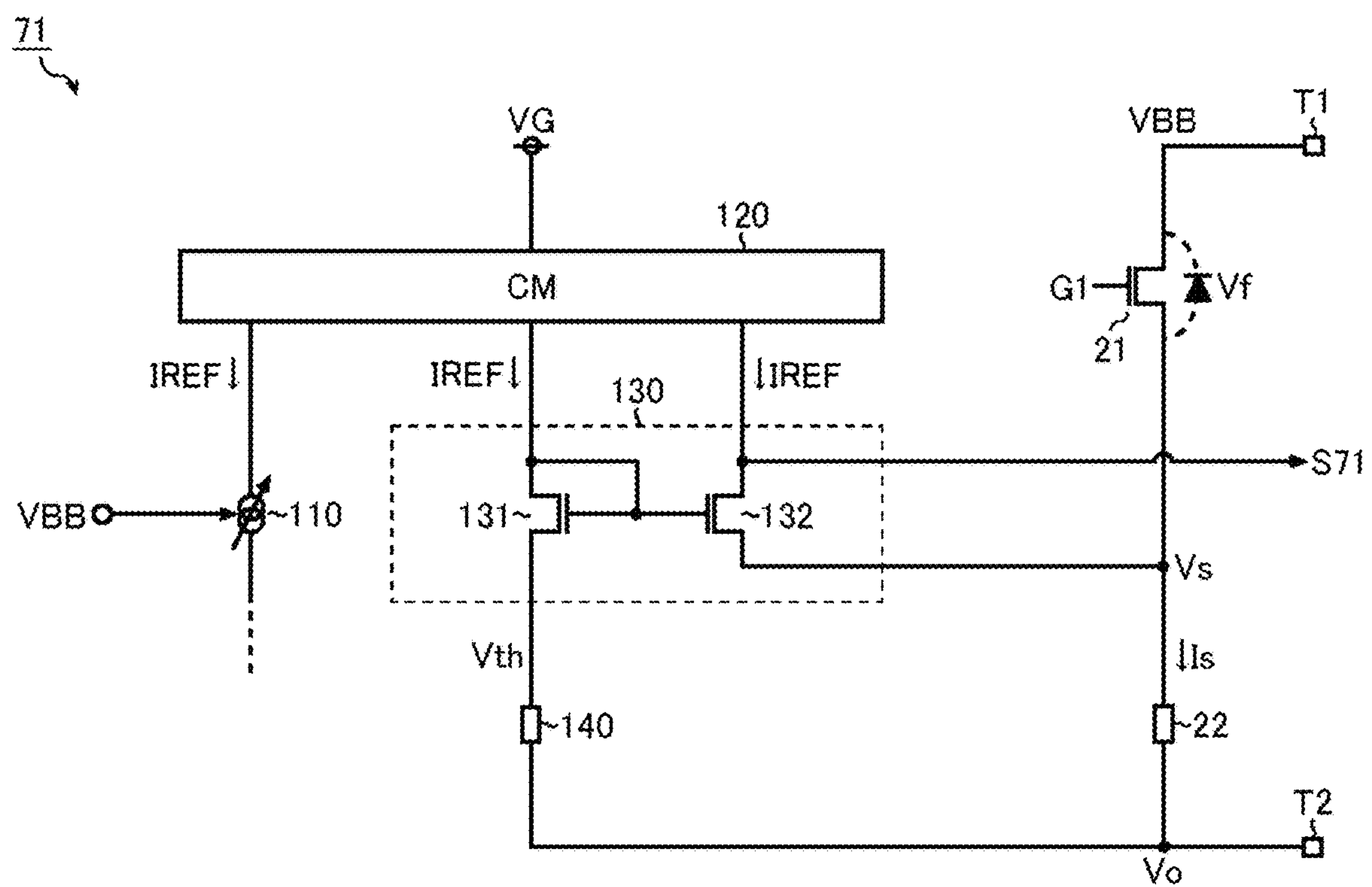


FIG. 3





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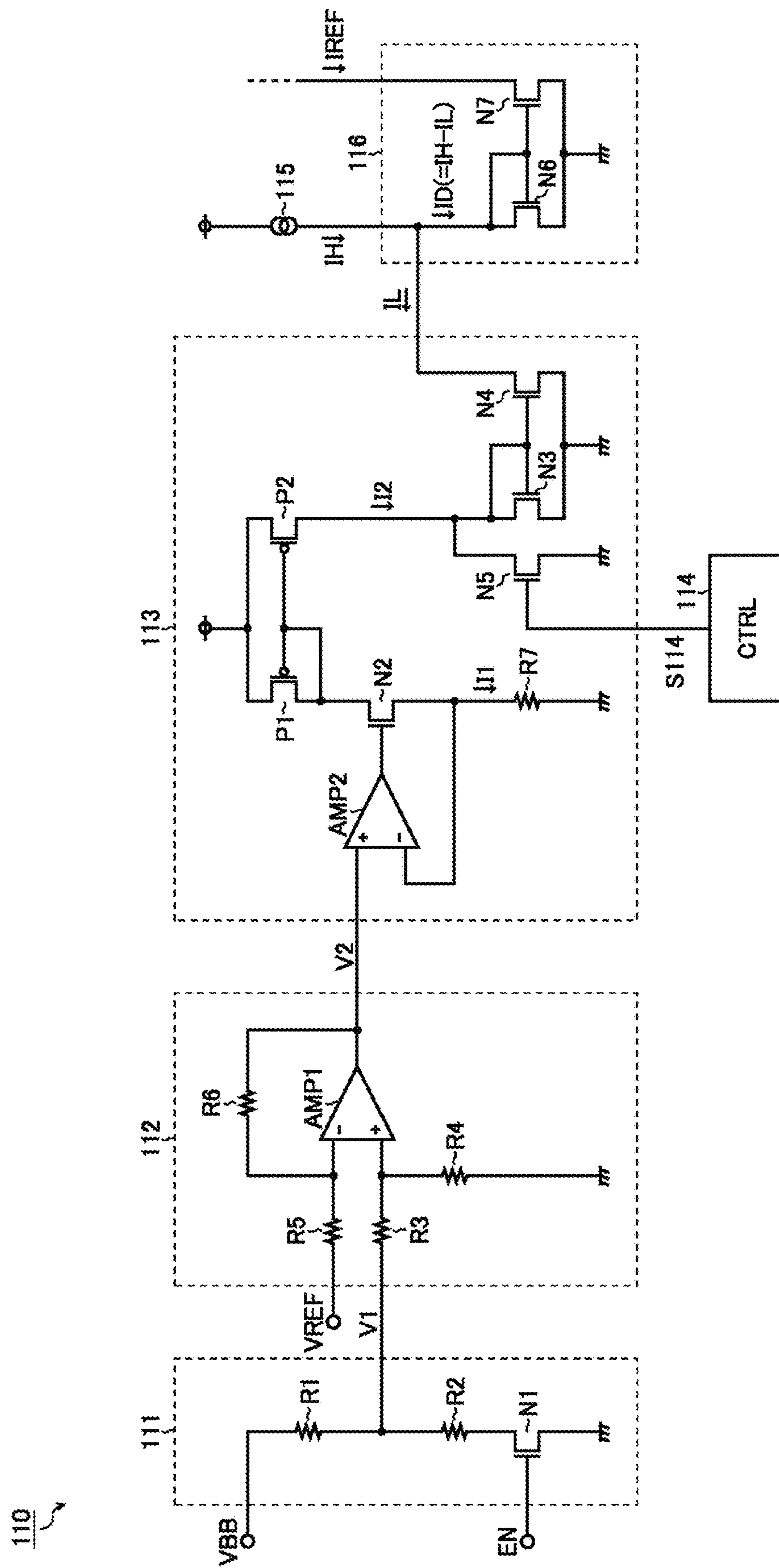


FIG. 5

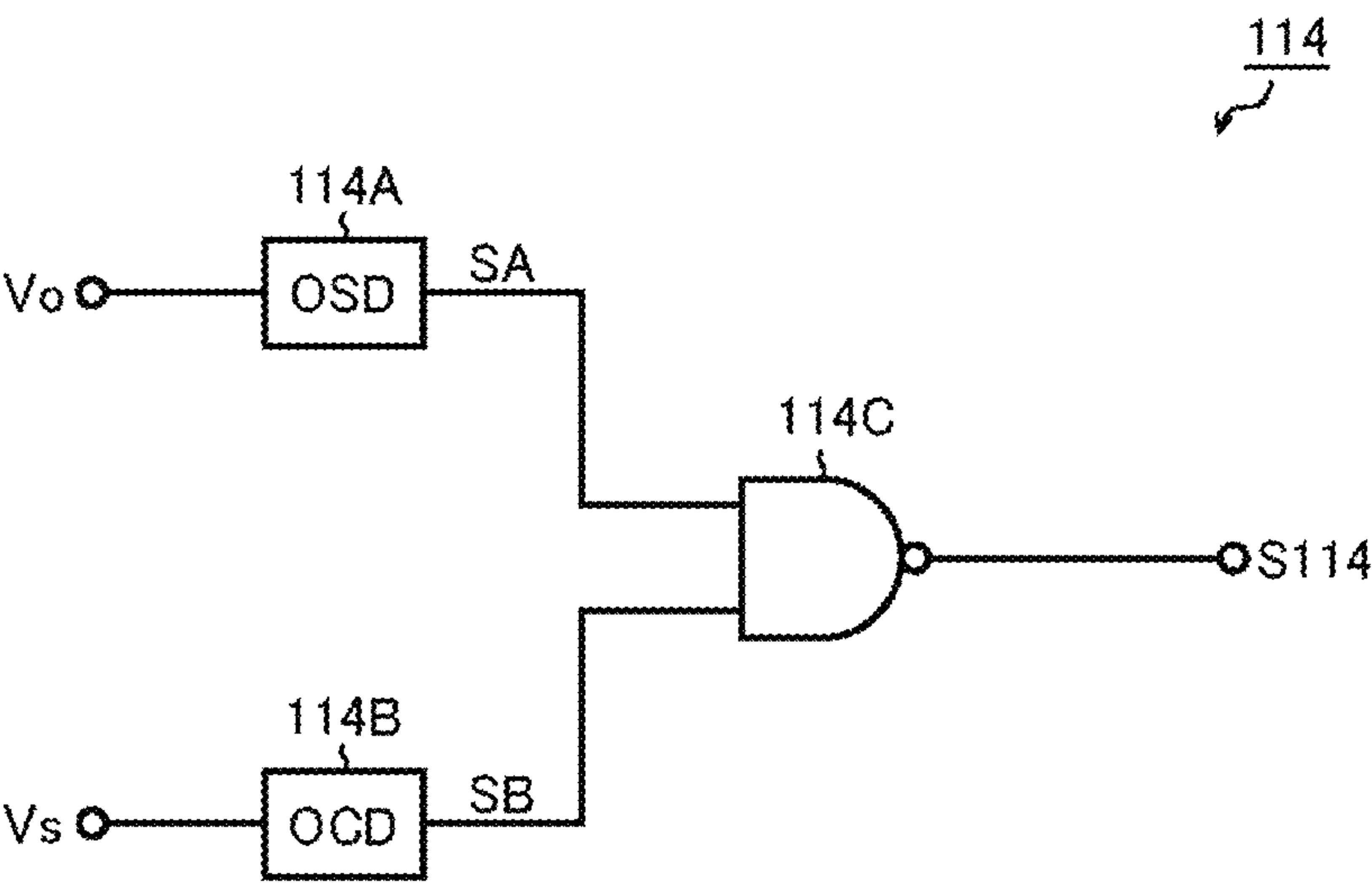


FIG. 6

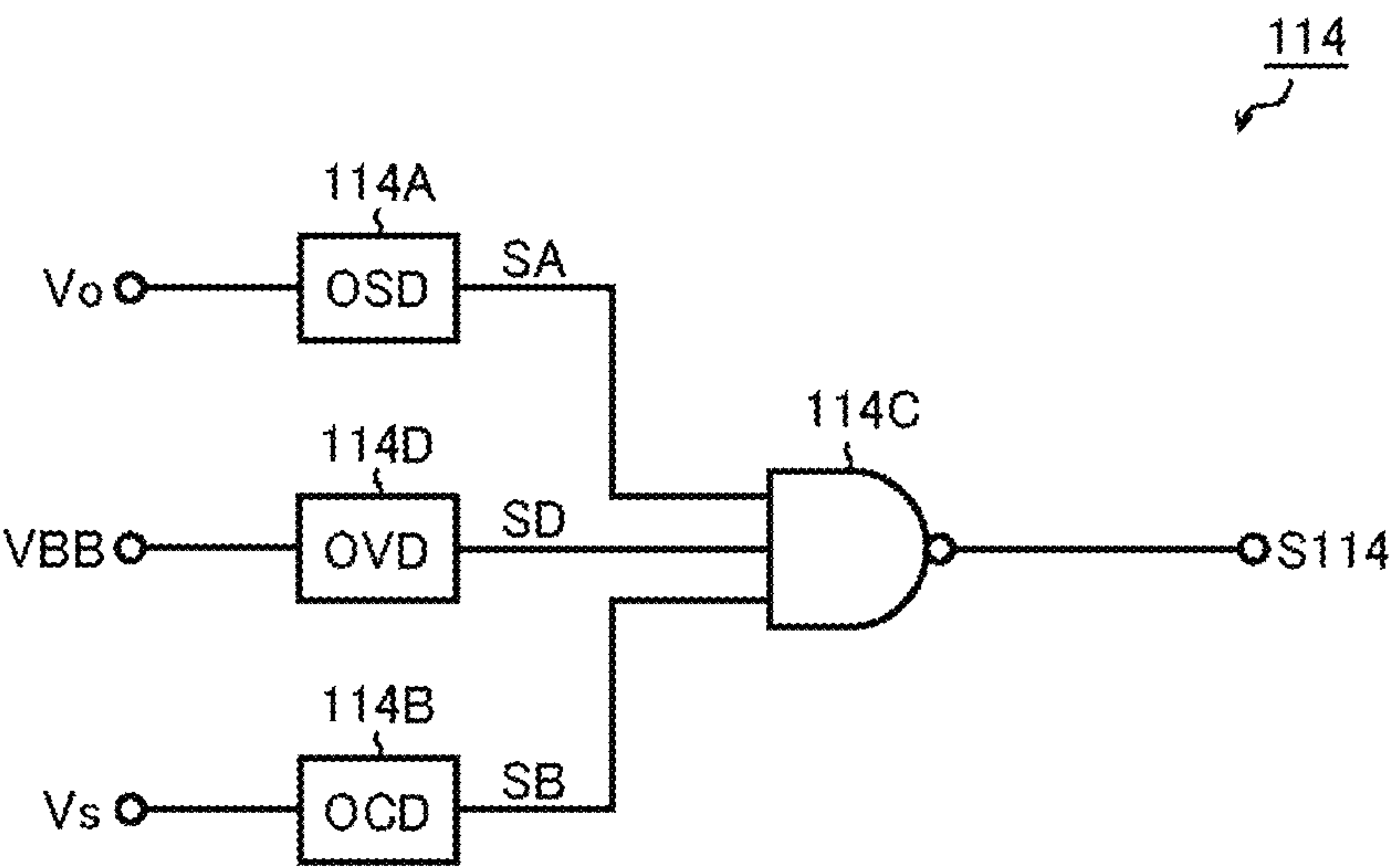




FIG. 7

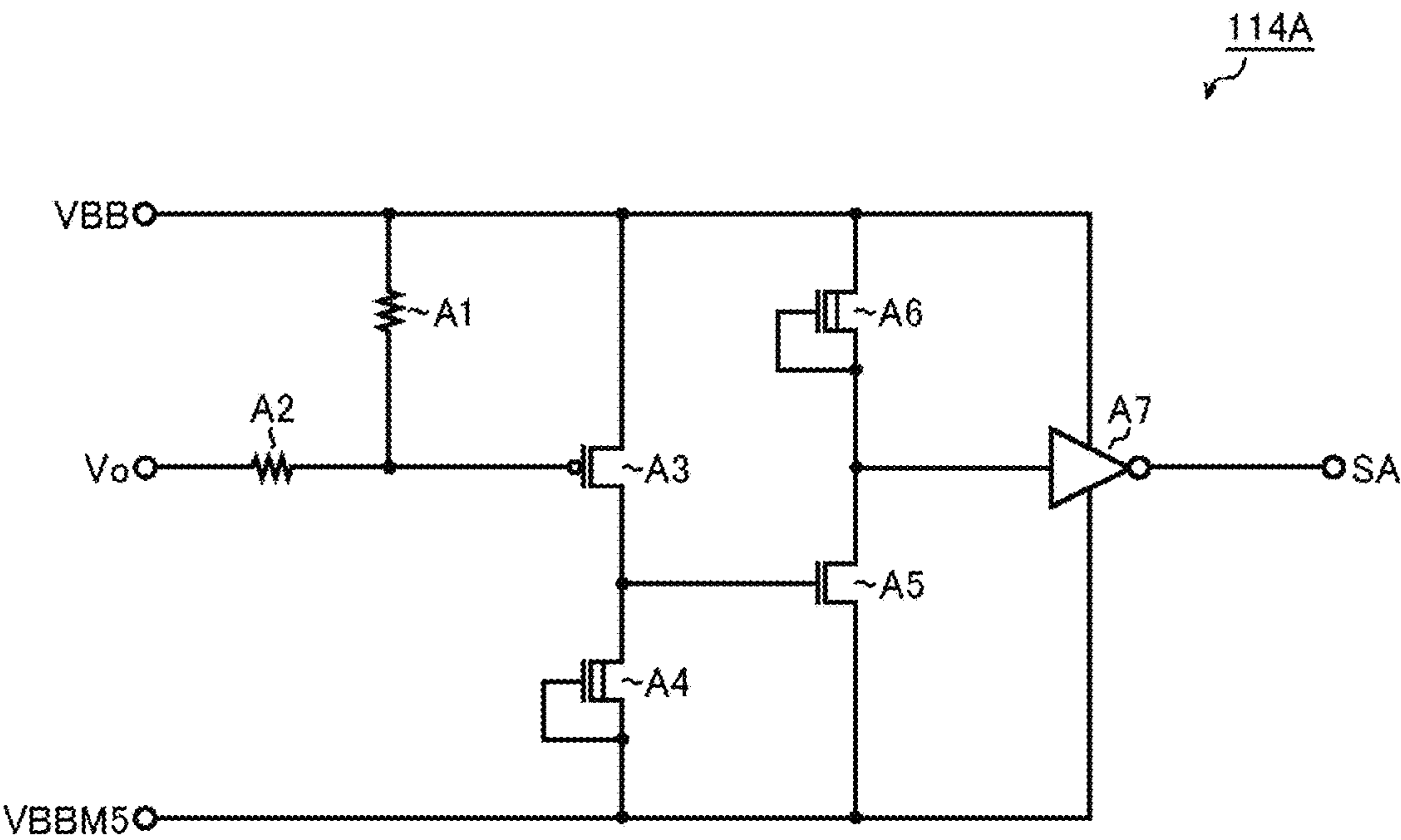


FIG. 8

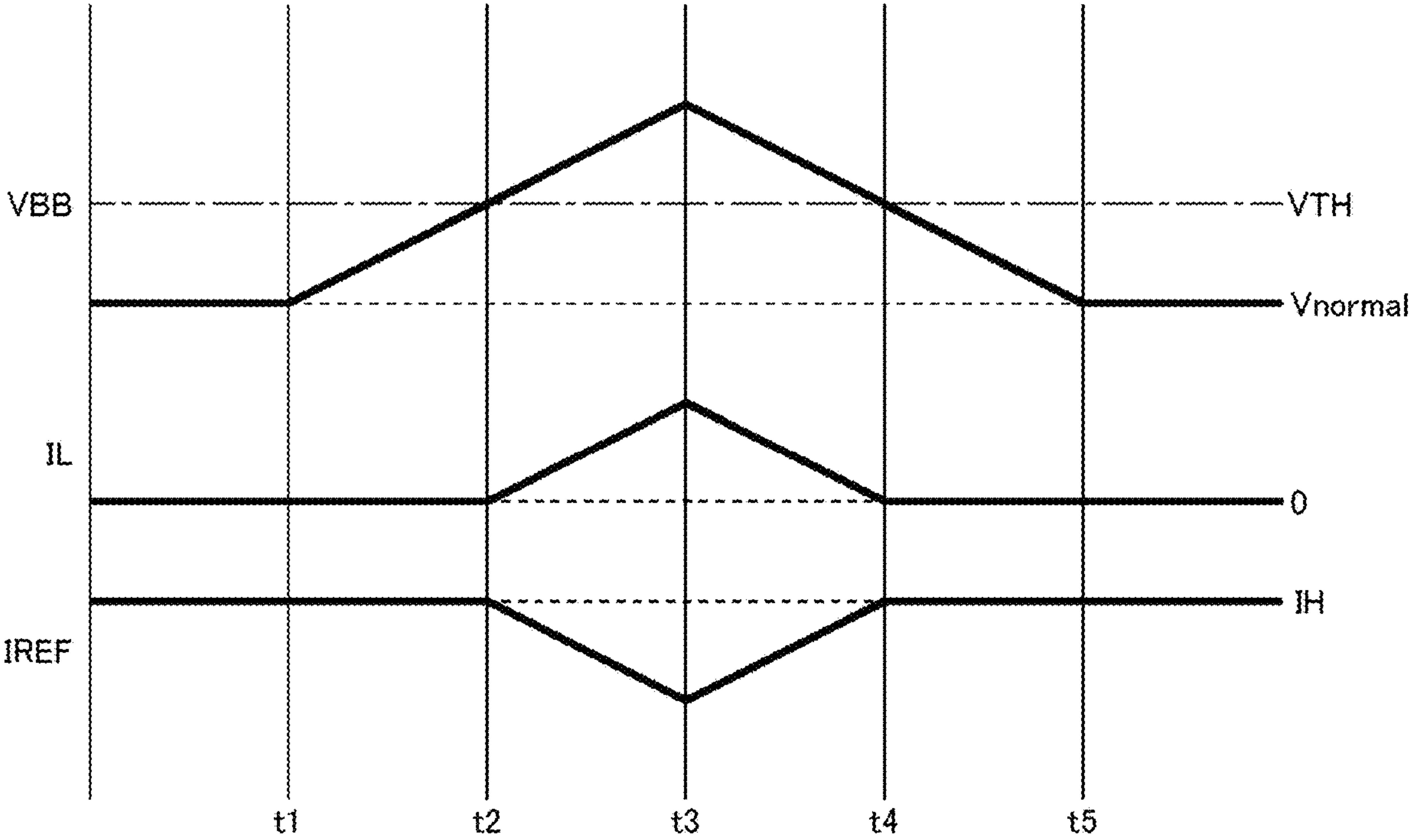


FIG. 9

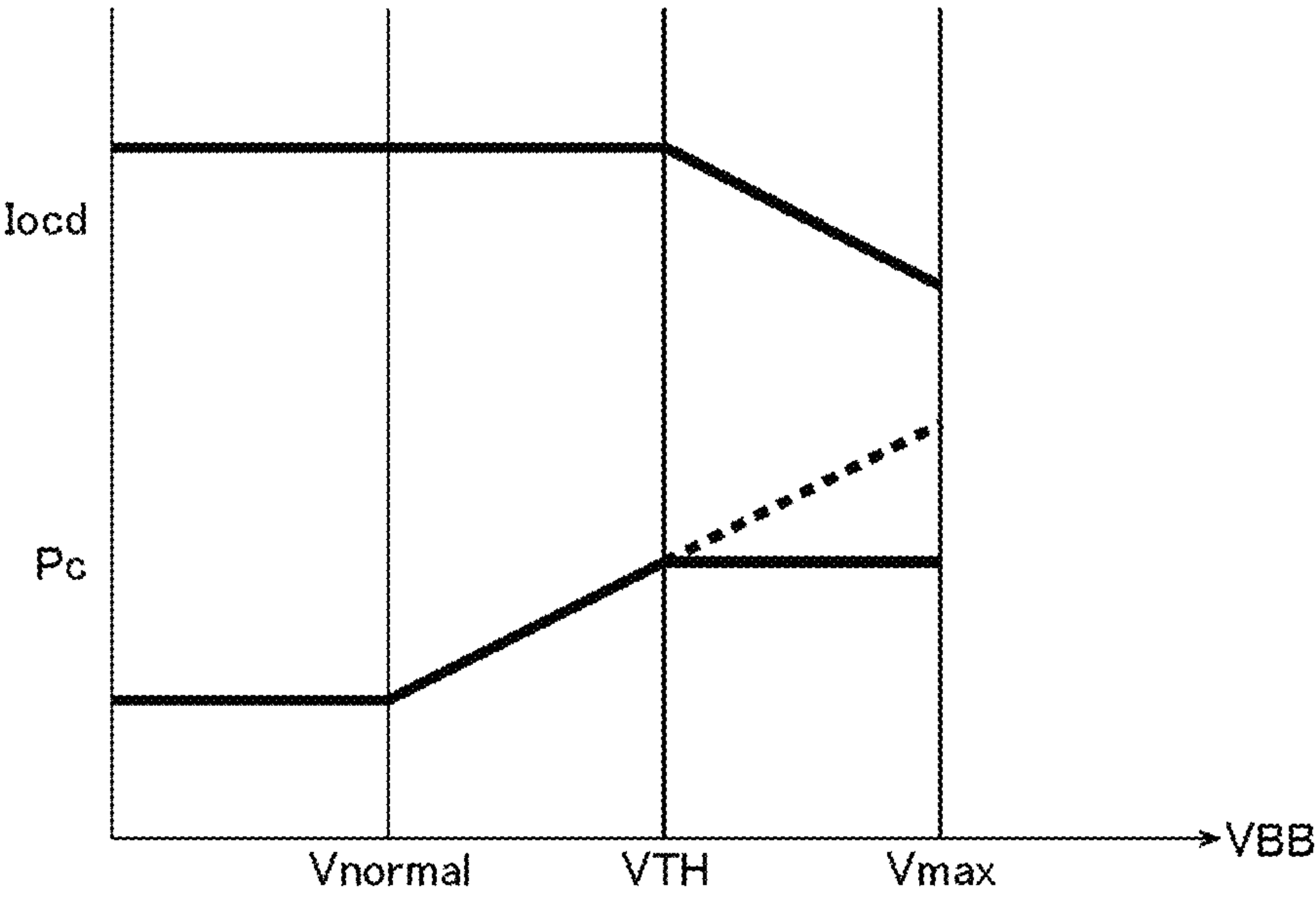


FIG. 10

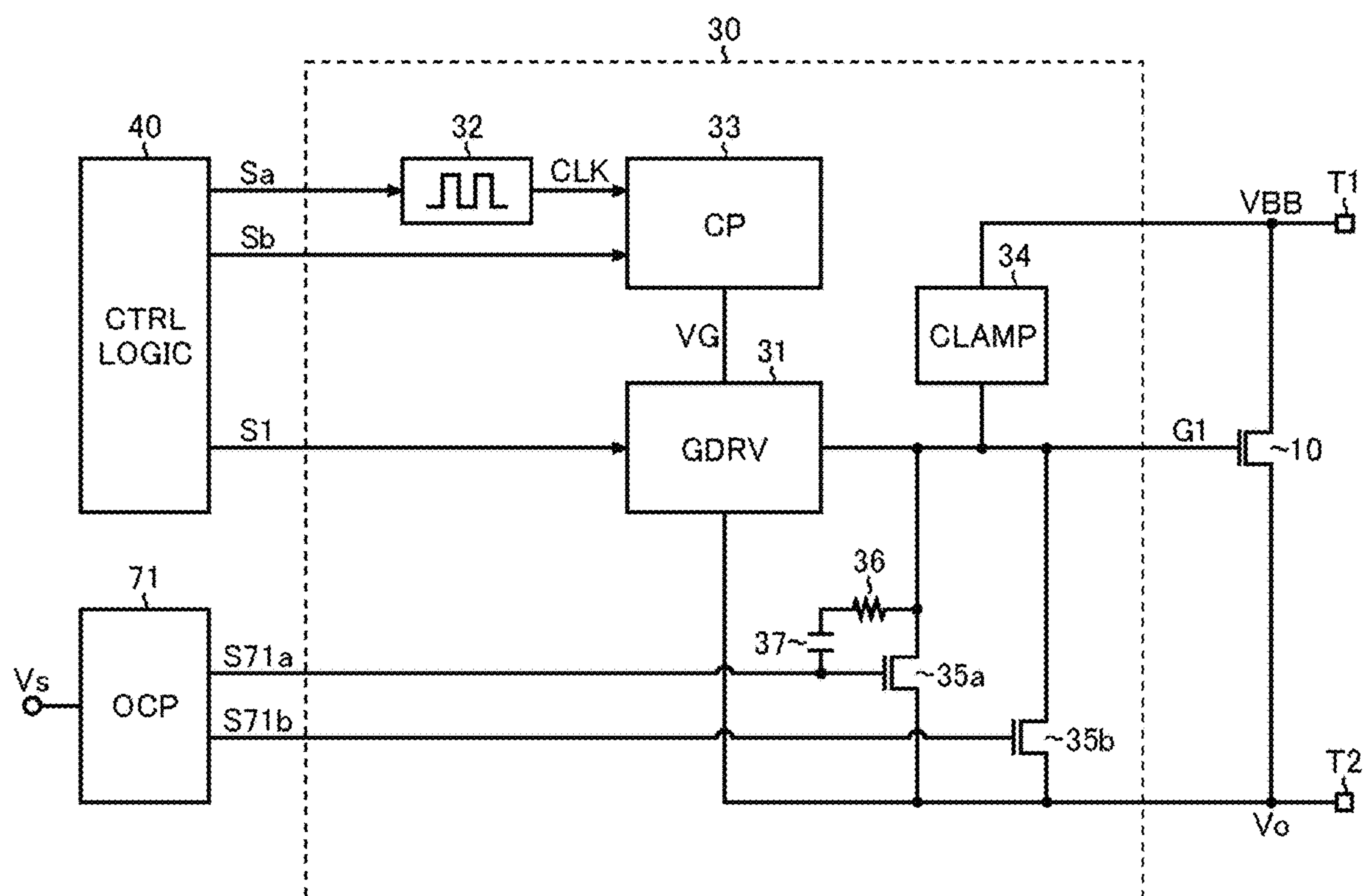


FIG. 11

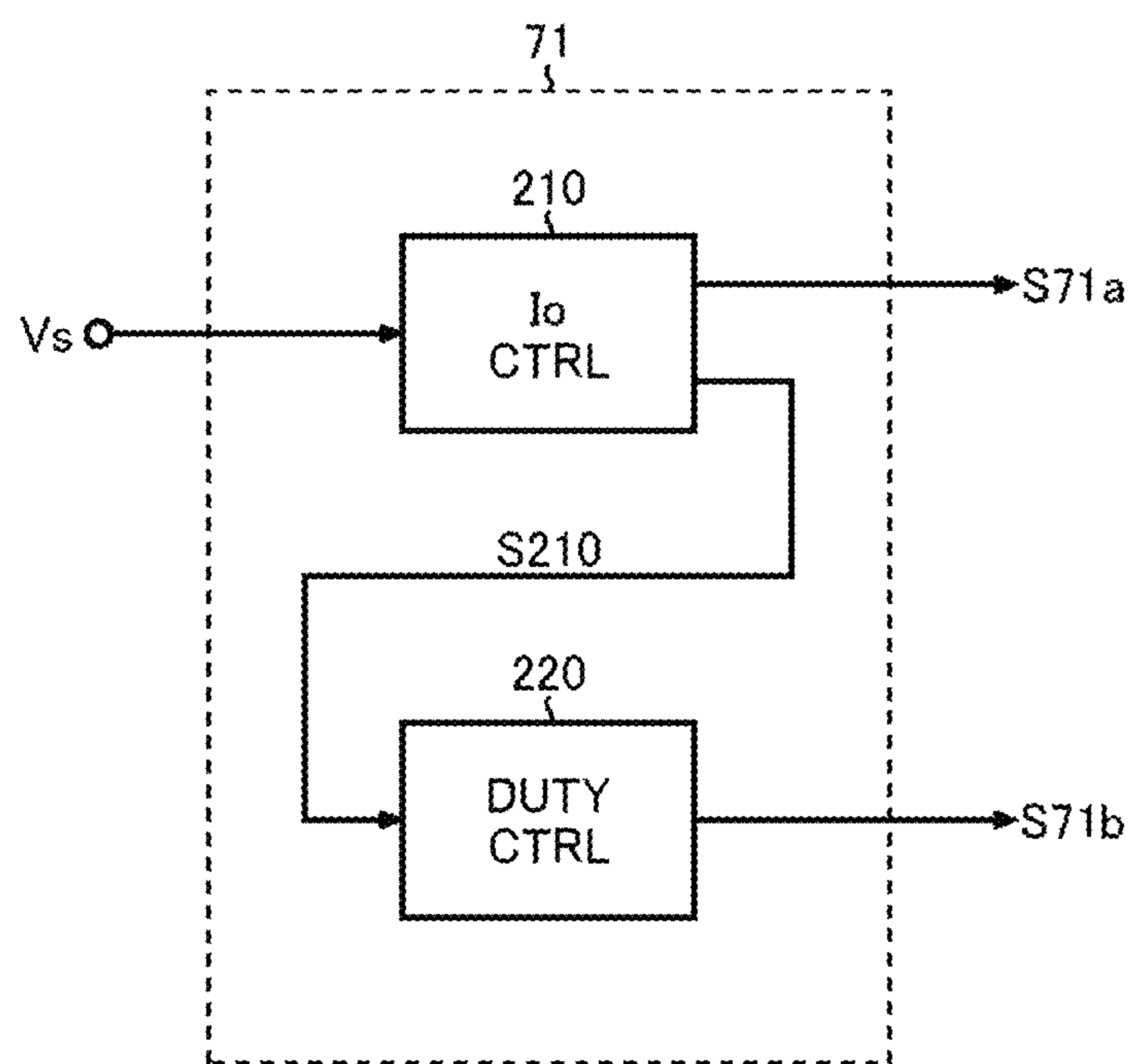


FIG. 12

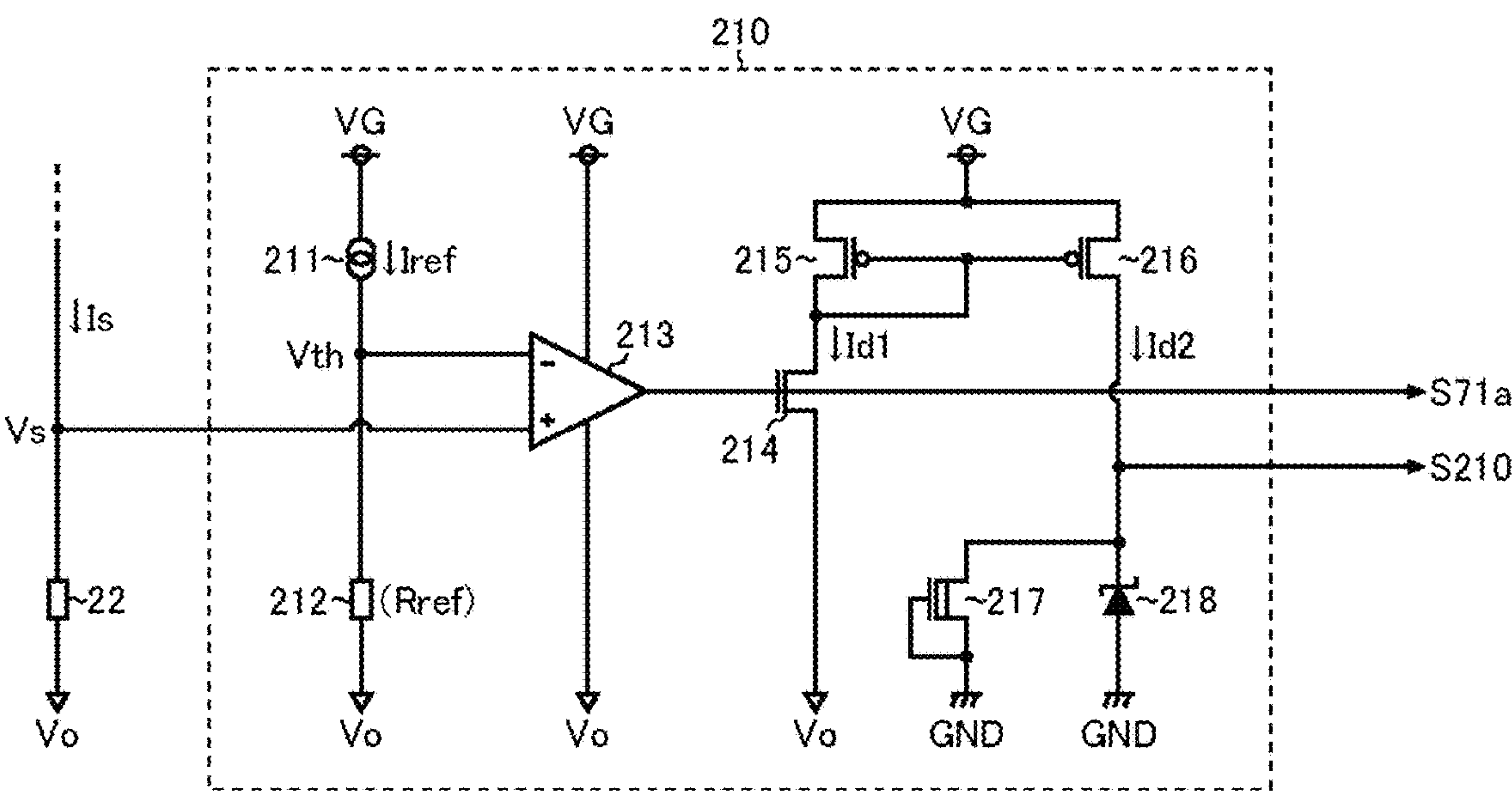




FIG. 13

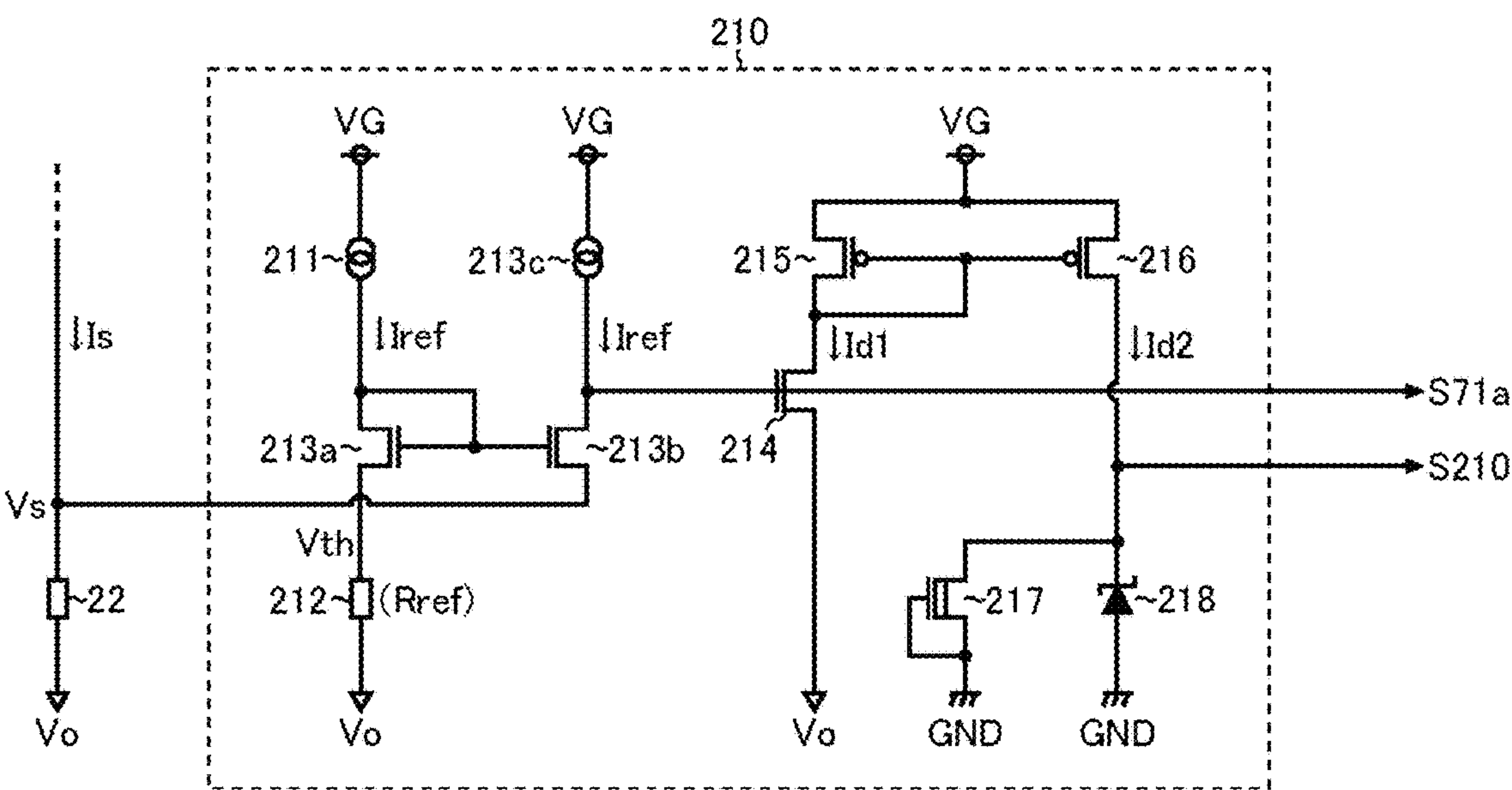


FIG. 14

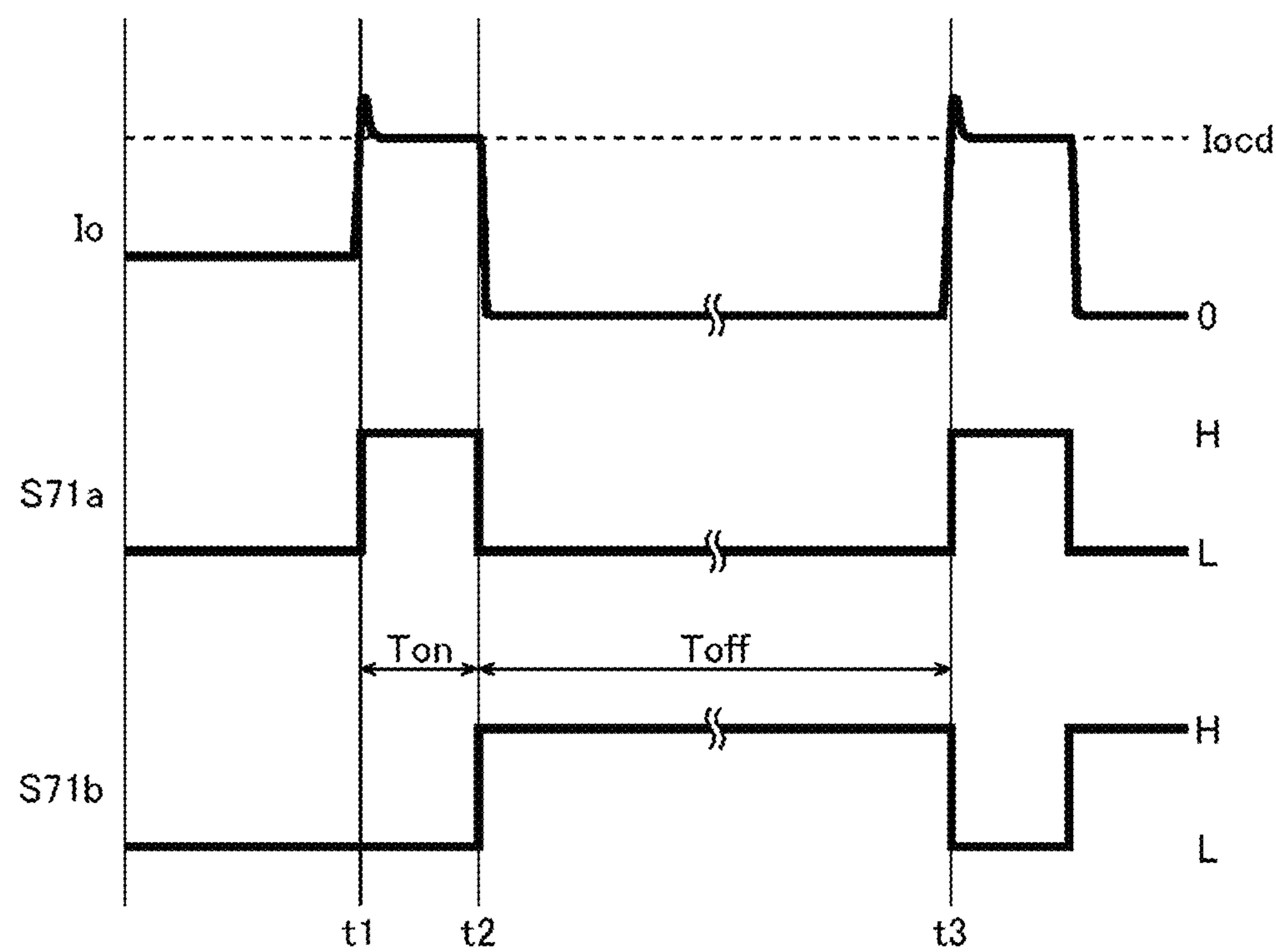


FIG. 15

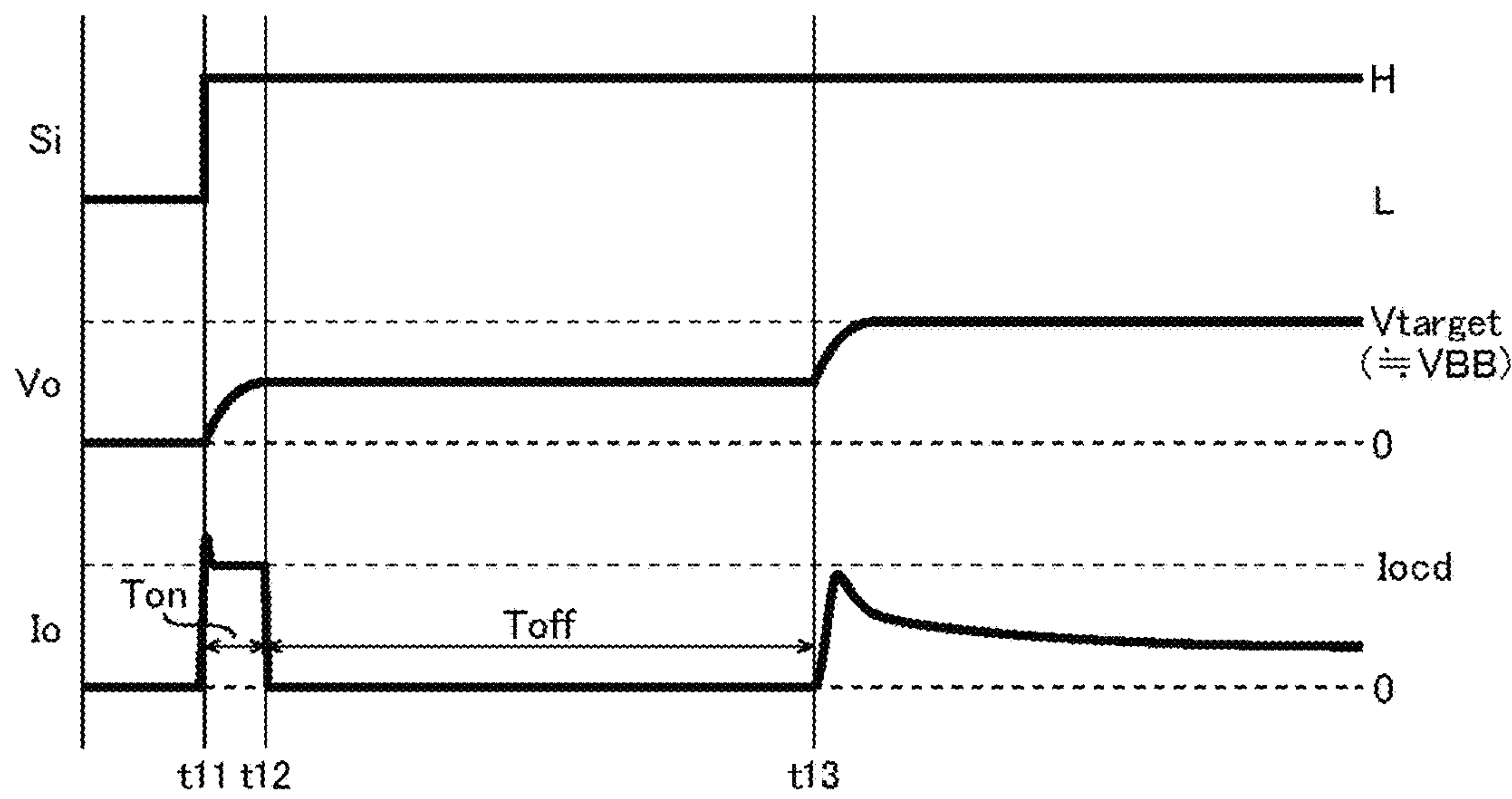


FIG. 16

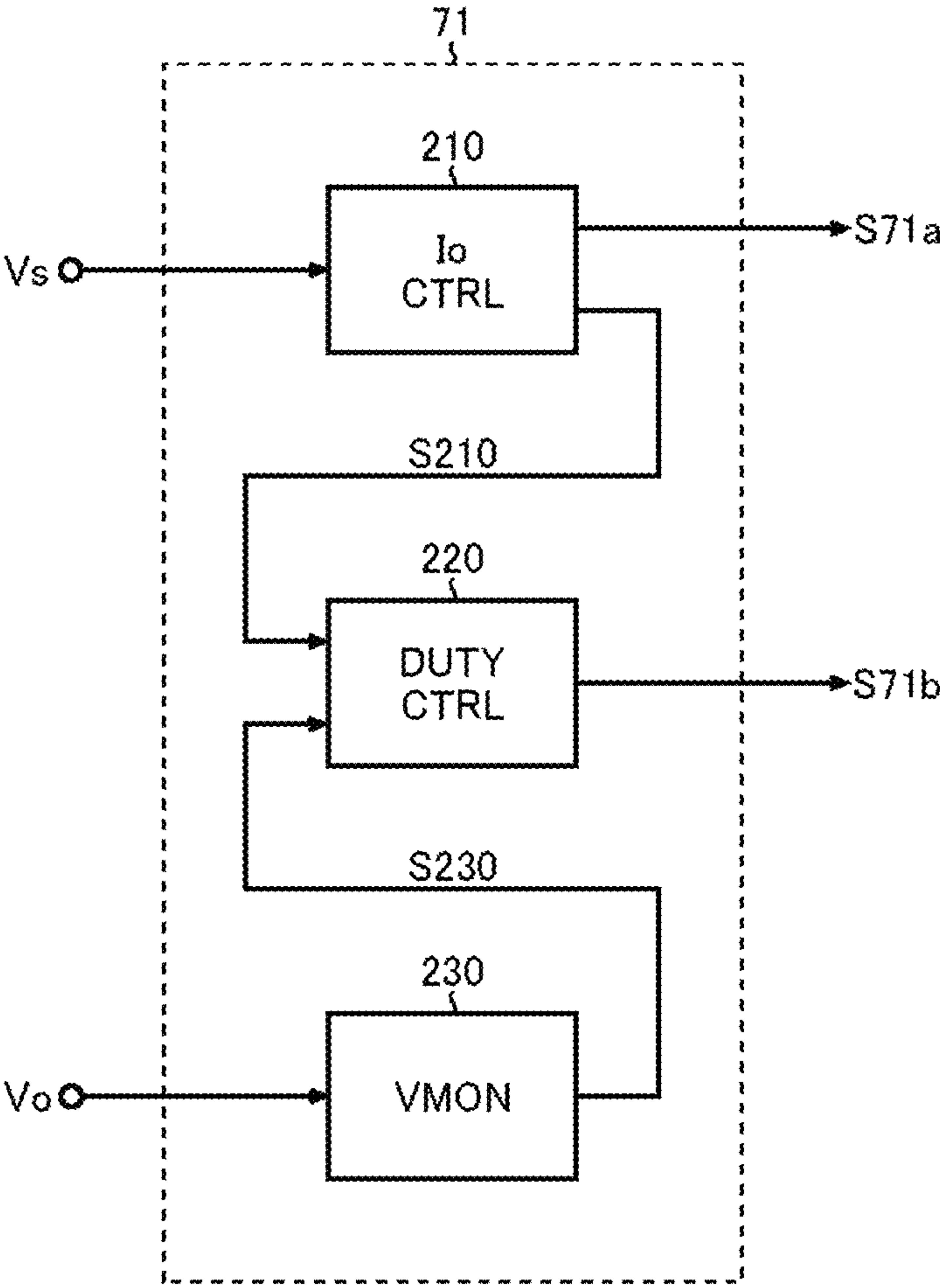


FIG. 17

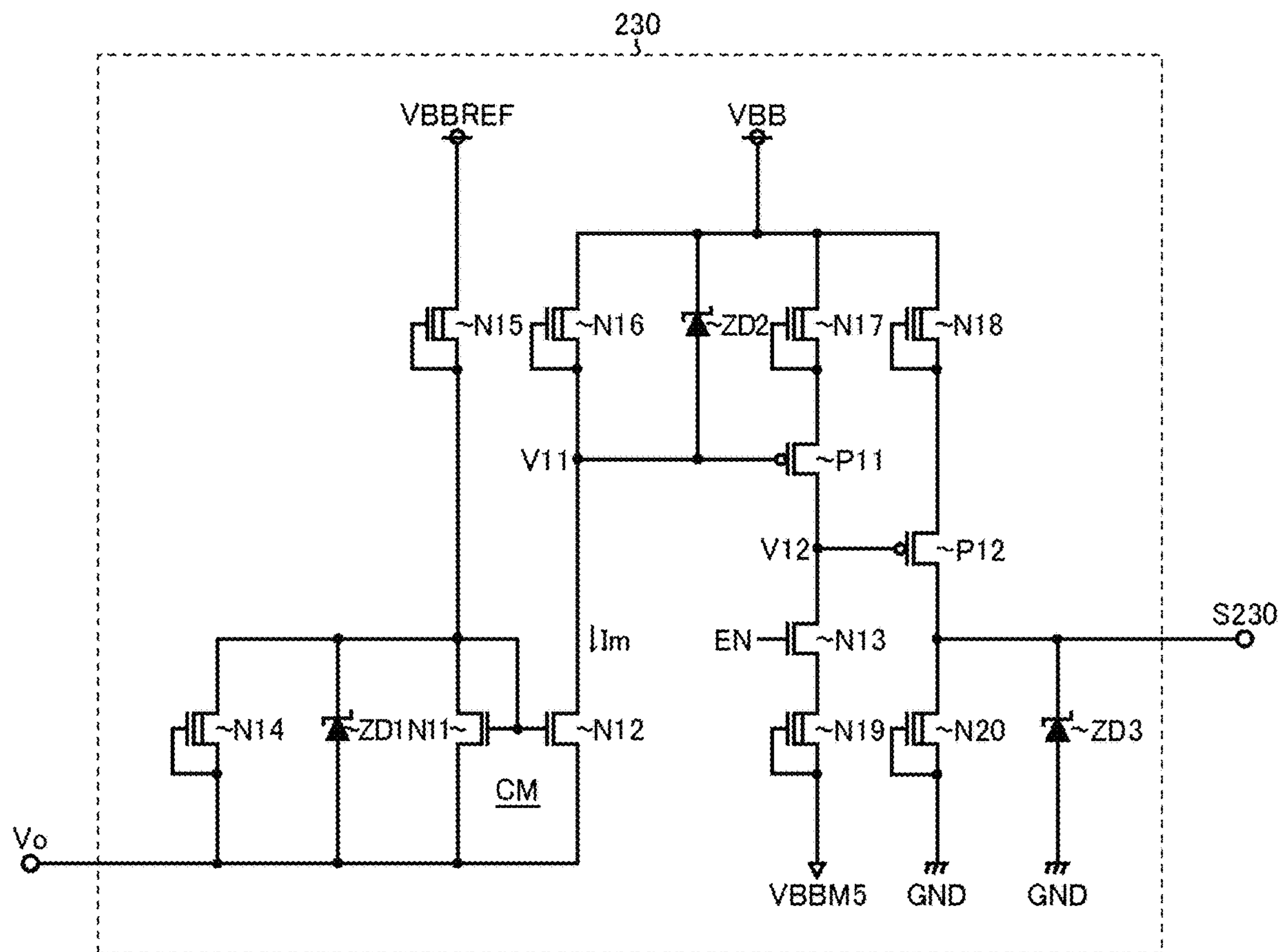


FIG. 18

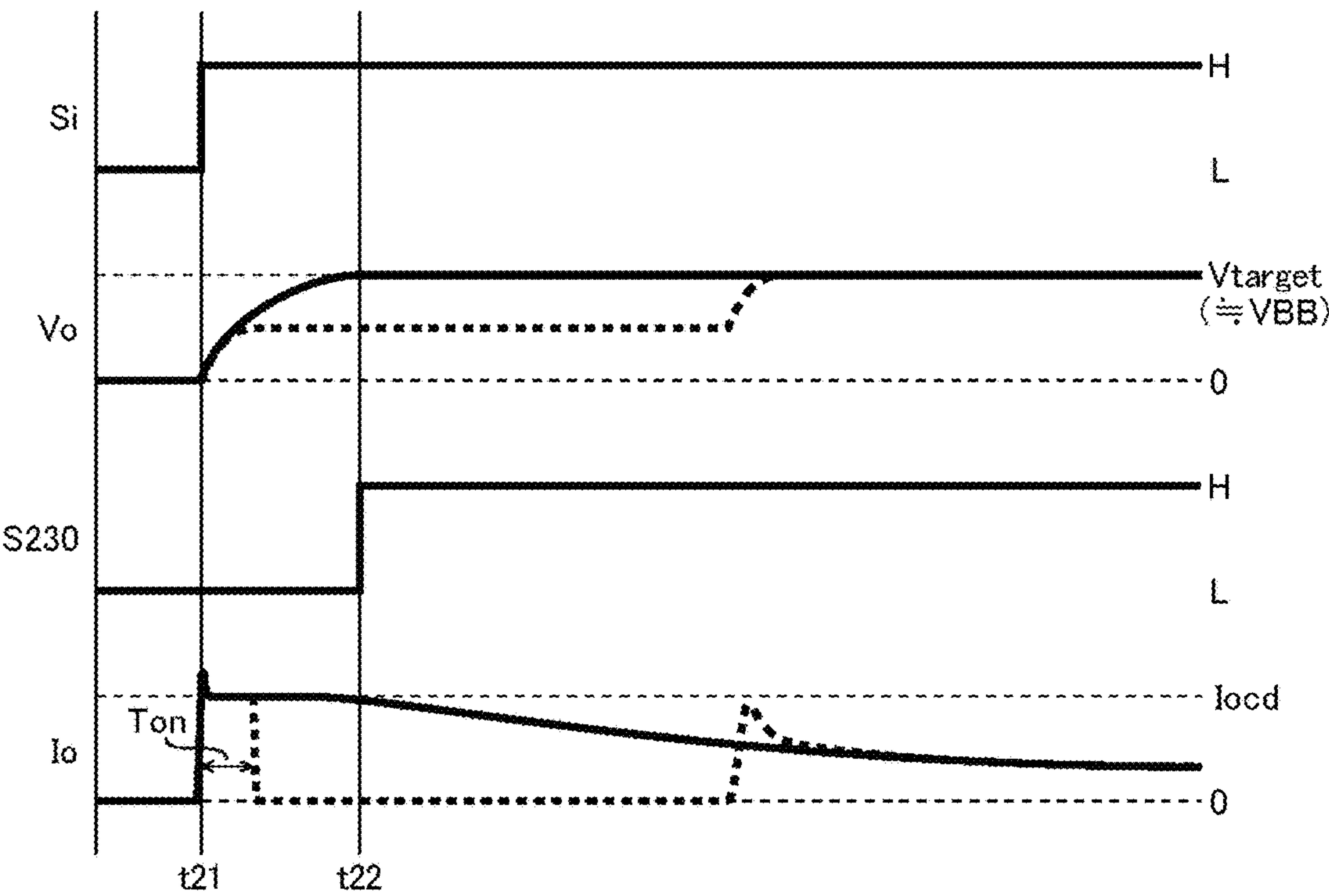




FIG. 19

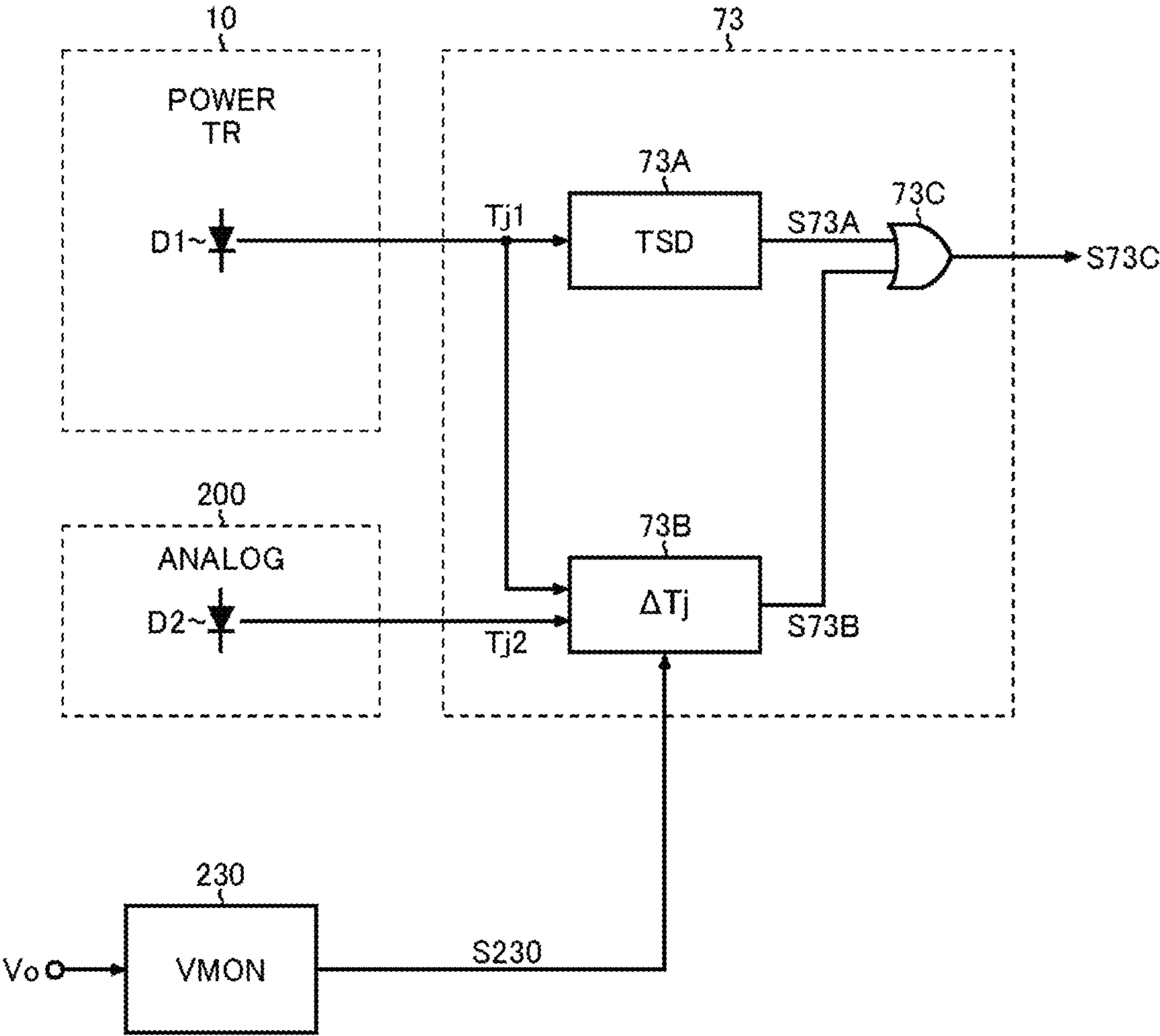
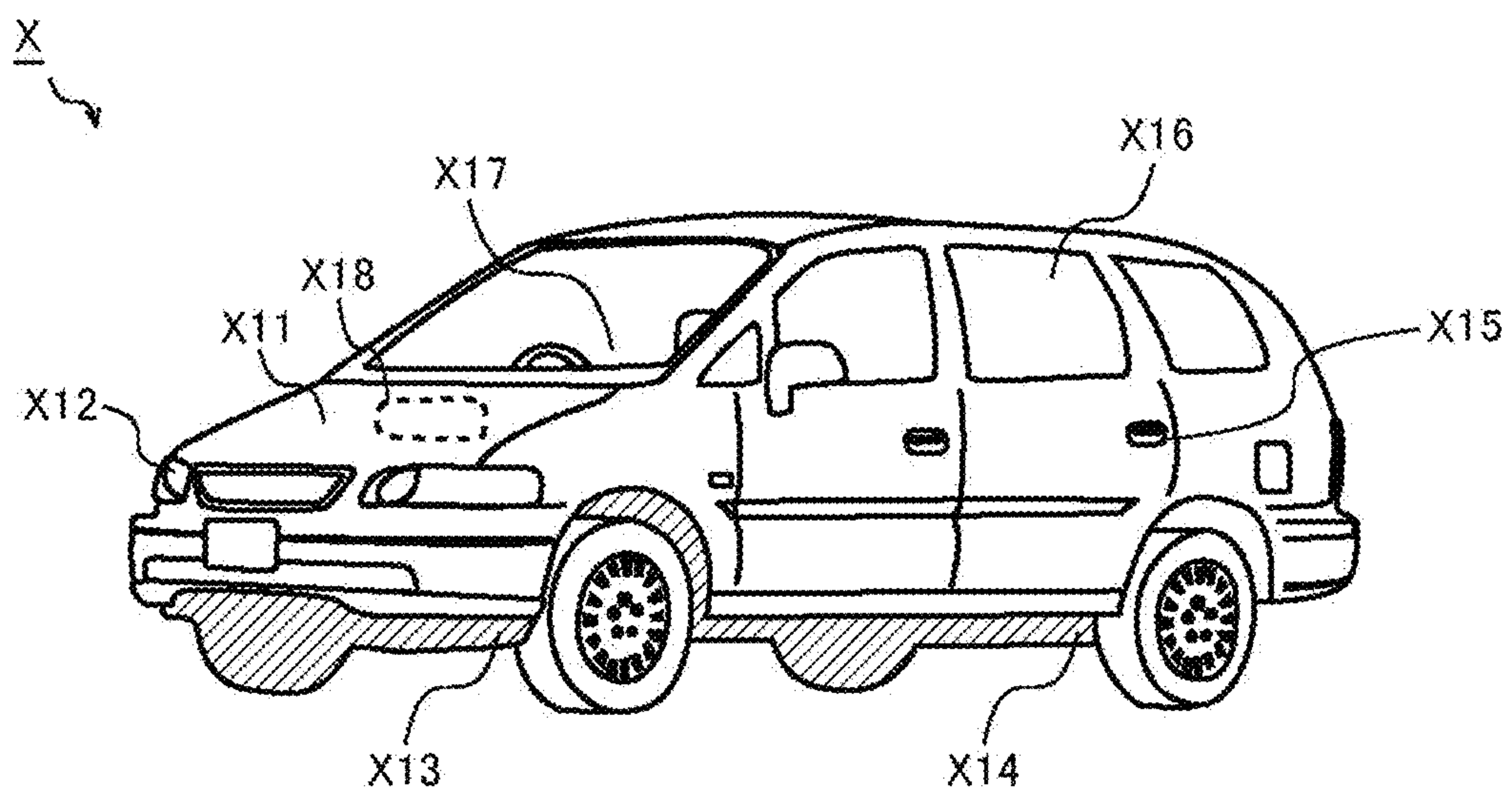


FIG. 20



# 1

## SWITCH DEVICE

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 17/552,783, filed Dec. 16, 2021, which is a divisional of U.S. application Ser. No. 16/218,724, filed Dec. 13, 2018, which claims priority under 35 U.S.C. § 119(a) on the following patent applications filed in Japan, the entire contents of which are hereby incorporated by reference.

- (1) No. 2017-240790 filed on Dec. 15, 2017
- (2) No. 2017-251264 filed on Dec. 27, 2017
- (3) No. 2018-198509 filed on Oct. 22, 2018

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The invention disclosed in this specification relates to a switch device.

#### Description of Related Art

Conventionally, switch devices (such as a high side switch IC and a low side switch IC), which are on/off controlled in accordance with an external control signal, are used in various applications.

As examples of conventional techniques related to the above description, there are JP-A-2015-35914 and JP-A-2016-208762.

However, in the conventional switch device, there is more room for improvement in reducing power consumption or keeping constant the same when an output short circuit occurs, or in compatibility between stable startup and functional safety thereof.

Particularly in recent years, in-vehicle ICs are required to comply with ISO26262 (international standard for functional safety of electric and electronic systems in vehicles), so it is important to design reliability based on fail-safe principle for in-vehicle switch devices, too.

### SUMMARY OF THE INVENTION

In view of the above-mentioned problem found by the inventors, it is an object of the invention disclosed in this specification to provide a switch device that can reduce power consumption or keep constant the same when an output short circuit occurs, or that can achieve both stable startup and functional safety.

A switch device disclosed in this specification includes switching element arranged to connect/disconnect a current path from a power supply terminal to a ground terminal via a load, and an overcurrent protection circuit arranged to limit output current flowing in the switching element to be an overcurrent limit value or less. When an output short circuit of the load is detected, the overcurrent protection circuit decreases the overcurrent limit value to be smaller as a power supply voltage is higher.

In addition, a switch device disclosed in this specification includes a switching element arranged to connect/disconnect a current path from a power supply terminal to a ground terminal via a load, an intermittent control unit arranged to intermittently drive the switching element when an abnormality is detected, and an output voltage monitoring portion arranged to disable the intermittent control unit until an output voltage applied to the load reaches its target value.

# 2

Note that other features, elements, steps, advantages, and characteristics of the present invention will become more apparent from the description of the best mode embodiment given below and the related attached drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustrating an overall structure of a semiconductor integrated circuit device.

FIG. 2 is a block diagram illustrating a first structural example of a gate control unit.

FIG. 3 is a structural example of an overcurrent protection circuit.

FIG. 4 is a diagram illustrating a structural example of a reference current generation portion.

FIG. 5 is a diagram illustrating a first structural example of a lower side current control unit.

FIG. 6 is a diagram illustrating a second structural example of the lower side current control unit.

FIG. 7 is a diagram illustrating a structural example of an output short circuit detection portion.

FIG. 8 is a timing chart illustrating linear control of a reference current.

FIG. 9 is a correlation diagram between a power supply voltage VBB and an overcurrent limit value Iocd as well as a power consumption Pc.

FIG. 10 is a block diagram illustrating a second structural example of the gate control unit.

FIG. 11 is a block diagram illustrating a first embodiment of the overcurrent protection circuit.

FIG. 12 is a circuit diagram illustrating a structural example of the current control unit.

FIG. 13 is a circuit diagram illustrating a variation of the current control unit.

FIG. 14 is a timing chart illustrating an example of the overcurrent protection operation.

FIG. 15 is a timing chart illustrating a manner in which a startup delay occurs.

FIG. 16 is a block diagram illustrating a second embodiment of the overcurrent protection circuit.

FIG. 17 is a circuit diagram illustrating a structural example of an output voltage monitoring portion.

FIG. 18 is a timing chart illustrating a manner in which the startup delay is cancelled.

FIG. 19 is a block diagram illustrating a structural example of a temperature protection circuit.

FIG. 20 is an external view illustrating a structural example of a vehicle.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

#### <Semiconductor Integrated Circuit Device>

FIG. 1 is a block diagram illustrating an overall structure of a semiconductor integrated circuit device. A semiconductor integrated circuit device 1 of this structural example is an in-vehicle high side switch IC (one type of an in-vehicle intelligent power device (IPD)), which connects/disconnects between an application terminal of a power supply voltage VBB and a load 3 in accordance with an instruction from an electronic control unit (ECU) 2.

Note that the semiconductor integrated circuit device 1 has external terminals T1 to T4 as means for establishing electric connection with outside of the device. The external terminal T1 is a power supply terminal (VBB pin) for receiving power supply voltage VBB (e.g. 12 V) from a battery (not shown). The external terminal T2 is a load



## 3

connection terminal (OUT pin) for externally connecting to the load 3 (one of a bulb lamp, a relay coil, a solenoid, a light emitting diode, a motor, and the like). The external terminal T3 is a signal input terminal (IN pin) for receiving external input of an external control signal Si from the ECU 2. The external terminal T4 is a signal output terminal (SENSE pin) for externally outputting a status signal So to the ECU 2. Note that an external sense resistor 4 is externally connected between the external terminal T4 and the ground terminal.

In addition, the semiconductor integrated circuit device 1 includes a NMOSFET 10, an output current monitoring portion 20, a gate control unit 30, a control logic portion 40, a signal input portion 50, an internal power supply portion 60, an abnormality protecting portion 70, an output current detection portion 80, and a signal output portion 90, which are integrated.

The NMOSFET 10 is a high withstand voltage (e.g. 42 V) power transistor having a drain connected to the external terminal T1 and a source connected to the external terminal T2. The NMOSFET 10 connected in this way functions as a switching element (high side switch) that connects/disconnects a current path from the application terminal of the power supply voltage VBB to the ground terminal via the load 3. The NMOSFET 10 is turned on when a gate drive signal G1 is at high level, and is turned off when the gate drive signal G1 is at low level.

Note that the NMOSFET 10 should be designed to have an on-resistance of a few mΩ to a few tens of mΩ. As the on-resistance of the NMOSFET 10 is smaller, overcurrent flows more easily so that abnormal heating occurs more easily when a short circuit to ground from the external terminal T2 occurs (i.e. a short circuit to the ground terminal or a similar low potential terminal). Therefore, as the on-resistance of the NMOSFET 10 is set lower, an overcurrent protection circuit 71 or a temperature protection circuit 73 described later becomes more important.

The output current monitoring portion 20 includes NMOSFETs 21 and 21' and a sense resistor 22, so as to generate a sense voltage Vs corresponding to an output current Io flowing in the NMOSFET 10.

The NMOSFETs 21 and 21' are mirror transistors connected in parallel to the NMOSFET 10, so as to respectively generate sense currents Is and Is' corresponding to the output current Io. A size ratio between the NMOSFET 10 and each of the NMOSFETs 21 and 21' is m:1 (m>1). Therefore, the sense currents Is and Is' have a value corresponding to 1/m of the output current Io. Note that each of the NMOSFETs 21 and 21' is turned on when the gate drive signal G1 is at high level, and is turned off when a gate voltage G2 is at low level, similarly to the NMOSFET 10.

The sense resistor 22 (having a resistance of Rs) is connected between the source of the NMOSFET 21 and the external terminal T2, and is a current to voltage conversion element that generates the sense voltage Vs corresponding to a sense current Is ( $V_s = I_s \times R_s + V_o$ , where  $V_o$  is an output voltage at the external terminal T2).

The gate control unit 30 generates the gate drive signal G1 whose current capacity is increased from that of a gate control signal S1 and outputs the gate drive signal G1 to the gates of the NMOSFETs 10 and 21, so as to perform on/off control of the NMOSFETs 10 and 21. Note that the gate control unit 30 has a function to control the NMOSFETs 10 and 21 so that the output current Io is limited according to an overcurrent protection signal S71.

The control logic portion 40 is supplied with an internal power supply voltage Vreg so as to generate the gate control signal S1. For instance, when the external control signal Si

## 4

is at high level (that is a logic level to turn on the NMOSFET 10), the internal power supply portion 60 supplies the internal power supply voltage Vreg, and the control logic portion 40 becomes an operating state so that the gate control signal S1 becomes high level (i.e. Vreg). On the contrary, when the external control signal S1 is at low level (that is a logic level to turn off the NMOSFET 10), the internal power supply portion 60 does not supply the internal power supply voltage Vreg, and the control logic portion 40 becomes a non-operating state so that the gate control signal S1 becomes low level (i.e. GND). In addition, the control logic portion 40 monitors various abnormality protection signals (the overcurrent protection signal S71, an open protection signal S72, a temperature protection signal S73, and a reduced voltage protection signal S74). Note that the control logic portion 40 also has a function to generate an output switch signal S2 according to the monitor results of the overcurrent protection signal S71, the open protection signal S72, and the temperature protection signal S73 among the abnormality protection signals described above.

The signal input portion 50 is a schmitt trigger that receives the external control signal S1 from the external terminal T3 and transmits it to the control logic portion 40 and the internal power supply portion 60. Note that the external control signal S1 becomes high level when turning on the NMOSFET 10 and becomes low level when turning off the NMOSFET 10, for example.

The internal power supply portion 60 generates the predetermined internal power supply voltage Vreg from the power supply voltage VBB and supplies it to individual portions of the semiconductor integrated circuit device 1. Note that the internal power supply portion 60 is enabled or disabled by the external control signal S1. More specifically, the internal power supply portion 60 becomes the operating state when the external control signal Si is at high level and becomes the non-operating state when the external control signal Si is at low level.

The abnormality protecting portion 70 is a circuit block that detects various abnormalities of the semiconductor integrated circuit device 1 and includes the overcurrent protection circuit 71, an open protection circuit 72, the temperature protection circuit 73, and a reduced voltage protection circuit 74.

The overcurrent protection circuit 71 generates the overcurrent protection signal S71 corresponding to a monitor result of the sense voltage Vs (i.e. whether or not an overcurrent abnormality of the output current Io is generated). Note that the overcurrent protection signal S71 becomes low level when no abnormality is detected and becomes high level when an abnormality is detected, for example.

The open protection circuit 72 generates an open protection signal S72 corresponding to a monitor result of the output voltage Vo (i.e. whether or not an open abnormality of the load 3 is generated). Note that the open protection signal S72 becomes low level when no abnormality is detected and becomes high level when an abnormality is detected, for example.

The temperature protection circuit 73 includes a temperature detection element (not shown) that detects a temperature abnormality of the semiconductor integrated circuit device 1 (particularly inside or in a vicinity of the NMOSFET 10), so as to generate the temperature protection signal S73 corresponding to a detection result thereof (i.e. whether or not a temperature abnormality is generated). Note that the temperature protection signal S73 becomes low level when



## 5

no abnormality is detected and becomes high level when an abnormality is detected, for example.

The reduced voltage protection circuit **74** (a so-called under voltage locked-out (UVLO) circuit) generates the reduced voltage protection signal **S74** corresponding to a monitor result of the power supply voltage **VBB** or the internal power supply voltage **Vreg** (i.e. whether or not a reduced voltage abnormality is generated). Note that the reduced voltage protection signal **S74** becomes low level when no abnormality is detected and becomes high level when an abnormality is detected, for example.

The output current detection portion **80** uses bias means (not shown) so as to make a source voltage of the NMOSFET **21'** coincide with the output voltage **Vo**, and thus sense current **Is'** ( $=I_o/m$ ) corresponding to the output current **Io** is generated and output to the signal output portion **90**.

The signal output portion **90** selects one of the sense current **Is'** (corresponding to a detection result of the output current **Io**) and a fixed voltage **V90** (corresponding to an abnormality flag, not shown in this diagram), on the basis of the output selection signal **S2**, so as to output the same to the external terminal **T4**. If the sense current **Is'** is selected and output, an output detection voltage **V80** (i.e.  $I_s \times R_4$ ) obtained by current-to-voltage conversion of the sense current **Is'** by the external sense resistor **4** (having a resistance of **R4**) is transmitted to the ECU **2** as the status signal **So**. Note that the output detection voltage **V80** is higher as the output current **Io** is larger and is lower as the output current **Io** is smaller. In contrast, if the fixed voltage **V90** is selected and output, the fixed voltage **V90** is transmitted to the ECU **2** as the status signal **So**. Note that the fixed voltage **V90** is preferably set to a voltage value higher than an upper limit value of the output detection voltage **V80**.

According to this signal output portion **90**, both the detection result of the output current **Io** and the abnormality flag can be transmitted to the ECU **2** by using the single status signal **So**, and hence it is possible to contribute to reduction in the number of external terminals. Note that when reading a current value of the output current **Io** from the status signal **So**, analog-to-digital (A/D) conversion of the status signal **So** is performed. In contrast, when reading the abnormality flag from the status signal **So**, a logic level of the status signal **So** is determined using a threshold value a little lower than the fixed voltage **V90**.

<Gate Control Unit (First Structural Example)>

FIG. **2** is a block diagram illustrating a first structural example of the gate control unit **30**. The gate control unit **30** of this structural example includes a gate driver **31**, an oscillator **32**, a charge pump **33**, a clamper **34**, an NMOSFET **35**, a resistor **36** (having a resistance of **R36**), and a capacitor **37** (having a capacitance of **C37**).

The gate driver **31** is connected between an output terminal of the charge pump **33** (i.e. an application terminal of a stepped-up voltage **VG**) and an external terminal **T2** (i.e. the application terminal of the output voltage **Vo**), so as to generate the gate drive signal **G1** whose current capacity is increased from that of the gate control signal **S1**. Note that the gate drive signal **G1** becomes high level (i.e. **VG**) when the gate control signal **S1** is at high level and becomes low level (i.e. **Vo**) when the gate control signal **S1** is at low level.

The oscillator **32** generates a clock signal **CLK** having a predetermined frequency and outputs it to the charge pump **33**. Note that the oscillator **32** is enabled or disabled by an enable signal **Sa** from the control logic portion **40**.

The charge pump **33** drives a flying capacitor using the clock signal **CLK** so as to generate the stepped-up voltage **VG** that is higher than the power supply voltage **VBB**. Note

## 6

that the charge pump **33** is enabled or disabled by an enable signal **Sb** from the control logic portion **40**.

The clamper **34** is connected between the external terminal **T1** (i.e. the application terminal of the power supply voltage **VBB**) and the gate of the NMOSFET **10**. In an application in which an inductive load **3** is connected to the external terminal **T2**, when the NMOSFET **10** is switched from on to off, a counter electromotive force of the load **3** makes the output voltage **Vo** be a negative voltage ( $<GND$ ). For this reason, the damper **34** (so-called active clamp circuit) is disposed for absorption of energy.

The drain of the NMOSFET **35** is connected to the gate of the NMOSFET **10**. The source of the NMOSFET **35** is connected to the external terminal **T2**. The gate of the NMOSFET **35** is connected to the application terminal of the overcurrent protection signal **S71**. In addition, the resistor **36** and the capacitor **37** are connected in series between the drain and gate of the NMOSFET **35**.

When the overcurrent protection signal **S71** is raised to high level in the gate control unit **30** of this structural example, the gate drive signal **G1** is decreased from high level (i.e. **VG**) in the normal state with a predetermined time constant  $\tau (=R_{36} \times C_{37})$ . As a result, a conduction degree of the NMOSFET **10** is gradually decreased, and hence the output current **Io** is limited. On the contrary, when the overcurrent protection signal **S71** is reduced to low level, the gate drive signal **G1** is increased with the predetermined time constant  $\tau$ . As a result, the conduction degree of the NMOSFET **10** is gradually increased, and hence the limitation of the output current **Io** is cancelled.

In this way, the gate control unit **30** of this structural example has a function to control the gate drive signal **G1** so that the output current **Io** is limited according to the overcurrent protection signal **S71**.

<Current Protection Circuit>

FIG. **3** is a diagram illustrating a structural example of the overcurrent protection circuit **71**. The overcurrent protection circuit **71** of this structural example includes a reference current generation portion **110**, a current mirror **120**, a comparison portion **130**, and a resistor **140** (having a resistance of **R140**).

The reference current generation portion **110** generates a reference current **IREF**. Note that the reference current generation portion **110** has a function to decrease the reference current **IREF** to be linearly smaller as the power supply voltage **VBB** is higher when an output short circuit of the load **3** is detected (i.e. when a short circuit to ground from the external terminal **T2** is detected in the case of high side switch IC). This point is described later.

The current mirror **120** mirrors the reference current **IREF** input to an input terminal and outputs the same from the first output terminal and the second output terminal, respectively.

The comparison portion **130** includes a pair of NMOSFETs **131** and **132** and has a structure as a co-called current mirror type comparator.

The gates of the transistors **131** and **132** are both connected to the drain of the transistor **131**. The drain of the transistor **131** is connected to a first output terminal of the current mirror **120** and flows the reference current **IREF**. The source of the transistor **131** is connected to a first terminal of the resistor **140** (corresponding to an application terminal of a threshold value voltage **Vth**). The second terminal of the resistor **140** is connected to the application terminal of the output voltage **Vo** (i.e. the external terminal **T2**). The drain of the transistor **132** is connected to a second output terminal of the current mirror **120** and flows the reference current **IREF**. The drain of the transistor **132** is connected also to an



output terminal of the overcurrent protection signal **S71**. The source of the transistor **132** is connected to the source of the NMOSFET **21** and a first terminal of the sense resistor **22** (i.e. an application terminal of the sense voltage  $V_s$ ). The second terminal of the sense resistor **22** is connected to the application terminal of the output voltage  $V_o$  (i.e. the external terminal **T2**). The drain of the NMOSFET **21** is connected to the application terminal of the power supply voltage  $V_{BB}$  (i.e. the external terminal **T1**).

The comparison portion **130** of this structural example operates using the output voltage  $V_o$  as a reference potential, and compares the threshold value voltage  $V_{th}$  corresponding to the reference current  $I_{REF}$  ( $V_{th}=I_{REF}\times R_{140}+V_o$ ) with the sense voltage  $V_s$  ( $=I_s\times R_s+V_o$ ) corresponding to the output current  $I_o$  (sense current  $I_s$ ), so as to generate the overcurrent protection signal **S71**. Note that the overcurrent protection signal **S71** becomes low level (i.e. a logic level when overcurrent is not detected) when the sense voltage  $V_s$  is lower than the threshold value voltage  $V_{th}$ , and becomes high level (i.e. a logic level when overcurrent is detected) when the sense voltage  $V_s$  is higher than the threshold value voltage  $V_{th}$ .

<Reference Current Generation Portion>

FIG. 4 is a diagram illustrating a structural example of the reference current generation portion **110**. The reference current generation portion **110** of this structural example includes a voltage divider portion **111**, a differential amplifier portion **112**, a lower side current generation portion **113**, a lower side current control unit **114**, an upper side current generation portion **115**, and a difference current generation portion **116**.

The voltage divider portion **111** includes resistors **R1** and **R2**, and an N-channel MOS field effect transistor **N1**, so as to generate a divided voltage  $V_1$  ( $=V_{BB}\times(R_2/(R_1+R_2))$ ) corresponding to the power supply voltage  $V_{BB}$ . The connection relationship of the components is as follows. A first terminal of the resistor **R1** is connected to the application terminal of the power supply voltage  $V_{BB}$ . A second terminal of the resistor **R1** and a first terminal of the resistor **R2** are connected to an output terminal of the divided voltage  $V_1$ . A second terminal of the resistor **R2** is connected to the drain of the transistor **N1**. The source of the transistor **N1** is connected to the ground terminal. The gate of the transistor **N1** is connected to an input terminal of an enable signal **EN**.

The transistor **N1** is turned on when the enable signal **EN** is at high level, and is turned off when the enable signal **EN** is at low level. Therefore, the voltage divider portion **111** is enabled or disabled according to the enable signal **EN**. As the enable signal **EN**, it is possible to use the external control signal **S1**, for example, which is transmitted from the external terminal **T3** via the signal input portion **50**.

If the power supply voltage  $V_{BB}$  is within an input dynamic range of the differential amplifier portion **112**, the voltage divider portion **111** can be eliminated, and the power supply voltage  $V_{BB}$  can be directly input to the differential amplifier portion **112**.

The differential amplifier portion **112** includes an operational amplifier **AMP1** and resistors **R3** to **R6**, and it amplifies a difference value between the divided voltage  $V_1$  and the predetermined reference voltage  $V_{REF}$  so as to generate a differential amplified voltage  $V_2$ . The connection relationship of the components is as follows. A first terminal of the resistor **R3** is connected to an input terminal of the divided voltage  $V_1$ . A second terminal of the resistor **R3** and a first terminal of the resistor **R4** are connected to a non-inverting input terminal (+) of the operational amplifier **AMP1**. A second terminal of the resistor **R4** is connected to

the ground terminal. A first terminal of the resistor **R5** is connected to an input terminal of the reference voltage  $V_{REF}$ . A second terminal of the resistor **R5** and a first terminal of the resistor **R6** are connected to an inverting input terminal (−) of the operational amplifier **AMP1**. A second terminal of the resistor **R6** is connected to an output terminal of the operational amplifier **AMP1** (i.e. an output terminal of the differential amplified voltage  $V_2$ ).

In the differential amplifier portion **112** having the structure described above, the differential amplified voltage  $V_2$  can be calculated using the following equation (1).

[Mathematical 1]

$$V_2 = \frac{R_2 \cdot R_4 \cdot (R_5 + R_6)}{(R_1 + R_2) \cdot (R_3 + R_4) \cdot R_5} V_{BB} - \frac{R_6}{R_5} V_{REF} = \alpha V_{BB} - \beta V_{REF} \quad (1)$$

$$\left( \alpha = \frac{R_2 \cdot R_4 \cdot (R_5 + R_6)}{(R_1 + R_2) \cdot (R_3 + R_4) \cdot R_5}, \beta = \frac{R_6}{R_5} \right)$$

The above equation (1) holds when the power supply voltage  $V_{BB}$  is higher than a predetermined threshold value voltage  $V_{TH}$  ( $=((\beta/\alpha) V_{REF})$ ), and  $V_2=0$  holds when the power supply voltage  $V_{BB}$  is lower than the threshold value voltage  $V_{TH}$ . In other words, when  $V_{BB}<V_{TH}$  holds, a lower side current  $I_L$  described later is zero.

Note that the threshold value voltage  $V_{TH}$  should be set to a voltage value (e.g. 30 V) that is higher than a normal value  $V_{normal}$  (e.g. 14 V) of the power supply voltage  $V_{BB}$  and is lower than a maximum rated value  $V_{max}$  (e.g. 40 V). According to this setting, as long as the power supply voltage  $V_{BB}$  has a normal value  $V_{normal}$  (or its approximate value), the reference current  $I_{REF}$  (therefore an overcurrent limit value  $I_{ocd}$  of the output current  $I_o$ ) is not decreased. Therefore, unnecessarily strict overcurrent limitation is not performed, and hence operational stability of the semiconductor integrated circuit device **1** is not lost.

The lower side current generation portion **113** includes an operational amplifier **AMP2**, N-channel MOS field effect transistors **N2** to **N5**, and P-channel MOS field effect transistors **P1** and **P2**, so as to generate the lower side current  $I_L$  corresponding to the differential amplified voltage  $V_2$ .

The connection relationship of the components is as follows. A non-inverting input terminal (+) of the operational amplifier **AMP2** is connected to an application terminal of the differential amplified voltage  $V_2$ . An inverting input terminal (−) of the operational amplifier **AMP2** and the source of the transistor **N2** are connected to a first terminal of a resistor **R7**. A second terminal of the resistor **R7** is connected to the ground terminal. An output terminal of the operational amplifier **AMP2** is connected to the gate of the transistor **N2**.

The operational amplifier **AMP2** connected in this way controls the gate of the transistor **N2** so that a virtual short circuit is formed between the non-inverting input terminal (+) and the inverting input terminal (−). As a result, a variable current  $I_1$  ( $=V_2/R_7$ ) corresponding to the differential amplified voltage  $V_2$  flows in the resistor **R7**. Note that the variable current  $I_1$  is larger as the differential amplified voltage  $V_2$  is higher, and is smaller as the differential amplified voltage  $V_2$  is lower.

The drain of the transistor **N2** is connected to the drain of the transistor **P1**. The gates of the transistors **P1** and **P2** are both connected to the drain of the transistor **P1**. The sources of the transistors **P1** and **P2** are both connected to the power supply terminal. The transistors **P1** and **P2** connected in this



way function as a first current mirror that outputs a mirror current  $I_2$  corresponding to the variable current  $I_1$  (e.g.  $I_2=I_1$ ) from the drain of the transistor P2.

The drain of the transistor P2 is connected to the drain of the transistor N3. The gates of the transistors N3 and N4 are both connected to the drain of the transistor N3. The sources of the transistors N3 and N4 are both connected to the ground terminal. The transistors N3 and N4 connected in this way function as a second current mirror that outputs the lower side current  $I_L$  corresponding to the mirror current  $I_2$  (e.g.  $I_L=I_2$ ) from the drain of the transistor N4.

The drain of the transistor N5 is connected to the drain of the transistor N3. The source of the transistor N5 is connected to the ground terminal. The gate of the transistor N5 is connected to an input terminal of a lower side current control signal S114. The transistor N5 connected in this way is turned on when the lower side current control signal S114 is at high level (i.e. a logic level when being disabled), and is turned off when the lower side current control signal S114 is at low level (i.e. a logic level when being enabled).

Note that when the transistor N5 is turned on, the gate and the source of each of the transistors N3 and N4 are short-circuited to each other, and hence the second current mirror is disabled. Therefore, the lower side current  $I_L$  is fixed to zero. On the contrary, when the transistor N5 is turned off, the gate and the source of each of the transistors N3 and N4 are disconnected from each other, and hence the second current mirror is enabled. In this case, the lower side current  $I_L$  has a current value corresponding to the mirror current  $I_2$  (therefore the variable current  $I_1$ ). As a result, the lower side current  $I_L$  is larger as the differential amplified voltage  $V_2$  is higher, and is smaller as the differential amplified voltage  $V_2$  is lower.

The lower side current control unit 114 generates the lower side current control signal S114 described above. Note that an internal structure of the lower side current control unit 114 is described later.

The upper side current generation portion 115 generates a predetermined upper side current  $I_H$ . Note that it is preferred to appropriately set the upper side current  $I_H$  according to an on-resistance and a withstand voltage of the NMOSFET 10, so that the semiconductor integrated circuit device 1 is not damaged even if an output short circuit of the load 3 occurs.

The difference current generation portion 116 includes N-channel MOS field effect transistors N6 and N7, and generates a difference current  $I_D$  ( $=I_H-I_L$ ) obtained by subtracting the lower side current  $I_L$  from the upper side current  $I_H$ , so as to output it as the reference current  $I_{REF}$ .

The connection relationship of the components is as follows. The drain of the transistor N6 is connected to an output terminal of the lower side current generation portion 113 (i.e. the drain of the transistor N4) and an output terminal of the upper side current generation portion 115. The gates of the transistors N6 and N7 are both connected to the drain of the transistor N6. The sources of the transistors N6 and N7 are both connected to the ground terminal. The transistors N6 and N7 connected in this way function as a third current mirror that outputs the reference current  $I_{REF}$  corresponding to the difference current  $I_D$  (e.g.  $I_{REF}=I_D$ ) from the drain of the transistor N7.

<Lower Side Current Control Unit>

FIG. 5 is a diagram illustrating a first structural example of the lower side current control unit 114. The lower side current control unit 114 of this structural example includes an output short circuit detection portion 114A, an overcurrent detection portion 114B, and a NAND gate 114C.

The output short circuit detection portion 114A monitors the output voltage  $V_o$  and detects an output short circuit of the load 3 (i.e. a short circuit to ground from the external terminal T2 in the case of the high side switch IC), so as to generate an output short circuit detection signal SA. The output short circuit detection signal SA becomes low level when no abnormality is detected, and becomes high level when an abnormality is detected.

The overcurrent detection portion 114B monitors the sense voltage  $V_s$  and detects an overcurrent abnormality of the output current  $I_o$ , so as to generate an overcurrent detection signal SB. The overcurrent detection signal SB becomes low level when no abnormality is detected, and becomes high level when an abnormality is detected. Note that the overcurrent detection portion 114B corresponds to the comparison portion 130 described above (see FIG. 3), and the overcurrent detection signal SB corresponds to the overcurrent protection signal S71.

The NAND gate 114C generates a NAND signal between the output short circuit detection signal SA and the overcurrent detection signal SB, and outputs it as the lower side current control signal S114. Therefore, the lower side current control signal S114 becomes high level (i.e. a logic level when being disabled) when at least one of the output short circuit detection signal SA and the overcurrent detection signal SB is at low level, and becomes low level (i.e. a logic level when being enabled) when both the output short circuit detection signal SA and the overcurrent detection signal SB are at high level.

In other words, the lower side current control unit 114 of this structural example generates the lower side current control signal S114, so as to stop output of the lower side current  $I_L$  when at least one of an output short circuit of the load 3 and an overcurrent abnormality of the output current  $I_o$  is not detected.

With this structure, in normal operation, the reference current  $I_{REF}$  (therefore the overcurrent limit value  $I_{ocd}$  of the output current  $I_o$ ) is not decreased. Consequently, unnecessarily strict overcurrent limitation is not performed, and hence operational stability of the semiconductor integrated circuit device 1 is not lost.

FIG. 6 is a diagram illustrating a second structural example of the lower side current control unit 114. The lower side current control unit 114 of this structural example is based on the first structural example (FIG. 5) and further includes an overvoltage detection portion 114D.

The overvoltage detection portion 114D monitors the power supply voltage  $V_{BB}$  and detects its overvoltage abnormality, so as to generate an overvoltage detection signal SD. The overvoltage detection signal SD becomes low level when no abnormality is detected, and becomes high level when an abnormality is detected. Note that as the overvoltage detection portion 114D, it is possible to use a comparator that compares the divided voltage  $V_1$  with a predetermined threshold value voltage  $V_{TH2}$  ( $= (R_2 / (R_1 + R_2)) V_{TH}$ ).

In other words, the lower side current control unit 114 of this structural example generates the lower side current control signal S114 so as to stop output of the lower side current  $I_L$ , not only when at least one of an output short circuit of the load 3 and an overcurrent abnormality of the output current  $I_o$  is not detected, but also when no overvoltage abnormality of the power supply voltage  $V_{BB}$  is detected.

With this structure, when  $V_{BB} < V_{TH}$  holds, even if the differential amplified voltage  $V_2$  is raised from zero because of a certain cause (such as an input offset of the operational



## 11

amplifier AMP1) so that the variable current I1 (and the mirror current I2 corresponding to the variable current I1) unintentionally flows out, the lower side current IL can be fixed to zero. Therefore, until VBB becomes higher than VTH, a decrease of the reference current IREF (therefore the overcurrent limit value Iocd of the output current Io) can be securely stopped.

<Output Short Circuit Detection Portion>

FIG. 7 is a diagram illustrating a structural example of the output short circuit detection portion 114A. The output short circuit detection portion 114A of this structural example includes resistors A1 and A2, a P-channel MOS field effect transistor A3, N-channel MOS field effect transistors A4 to A6, and an inverter A7. Note that the transistors A3 and A5 are enhancement types, and the transistors A4 and A6 are depletion types.

A first terminal of the resistor A1 is connected to the application terminal of the power supply voltage VBB (i.e. the external terminal T1). A first terminal of the resistor A2 is connected to the application terminal of the output voltage Vo (i.e. the external terminal T2). Second terminals of the resistors A1 and A2 are connected to the gate of the transistor A3. The source of the transistor A3 is connected to the application terminal of the power supply voltage VBB. The drain of the transistor A3 is connected to the drain of the transistor A4 and the gate of the transistor A5. The source and gate of the transistor A4 and the source of the transistor A5 are connected to an application terminal of a constant voltage VBBM5.

Note that the constant voltage VBBM5 is an internal voltage of the semiconductor integrated circuit device 1 and is approximately VBB-5 V.

The drain of the transistor A6 is connected to the application terminal of the power supply voltage VBB. The source and gate of the transistor A6 and the drain of the transistor A5 are connected to an input terminal of the inverter A7. An output terminal of the inverter A7 is connected to an output terminal of the output short circuit detection signal SA. A first power supply terminal of the inverter A7 (high potential side) is connected to the application terminal of the power supply voltage VBB. A second power supply terminal of the inverter A7 (low potential side) is connected to an application terminal of the constant voltage VBBM5.

In the output short circuit detection portion 114A of this structural example, when the output voltage Vo becomes lower than predetermined value (e.g. VBB-3 V), the transistor A3 is turned on, and the transistor A5 is turned on. As a result, an input signal to the inverter A7 becomes low level, and hence the output short circuit detection signal SA becomes high level (i.e. a logic level when an abnormality is detected).

In this way, the output short circuit detection portion 114A of this structural example can detect an output short circuit of the load 3 (i.e. a short circuit to ground from the external terminal T2) with a very simple circuit structure.

<Linear Control of Overcurrent Limit Value>

Next, technical meaning of introducing a linear control function of the overcurrent limit value Iocd is described in detail. In the semiconductor integrated circuit device 1, power consumption Pc of the NMOSFET 10 ( $P_c = I_o \times V_{ds}$ , where  $V_{ds}$  is a drain-source voltage of the NMOSFET 10) becomes maximum when an output short circuit of the load 3 occurs (a short circuit to ground in the high side switch IC, or a short circuit to power supply voltage in the low side switch IC).

## 12

Note that when an output short circuit of the load 3 occurs so that overcurrent limitation of the output current Io is performed,  $I_o = I_{ocd}$  holds, and  $V_{ds} = V_{BB}$  holds. As a result, the maximum value of the power consumption Pc (i.e.  $I_{ocd} \times V_{BB}$ ) is proportional to each of the overcurrent limit value Iocd of the output current Io and the power supply voltage VBB. Therefore, it is understood that the overcurrent limit value Iocd of the output current Io should be decreased, in order to reduce the power consumption Pc or keep constant the same when an output short circuit of the load 3 occurs.

However, the load 3 to be driven by the semiconductor integrated circuit device 1 may require an instantaneous large output current Io in the normal operation. For instance, an inrush current larger than normal operation current flows instantaneously in startup of a capacitive load such as a bulb lamp. Therefore, if the overcurrent limit value Iocd is simply set to a lower value, the load 3 may not be supplied with an appropriate output current Io, so that normal operation of the semiconductor integrated circuit device 1 may be interfered.

Therefore, it is important to set the overcurrent limit value Iocd to an original set value in the normal operation of the semiconductor integrated circuit device 1, and to appropriately decrease the overcurrent limit value Iocd from the original set value when it is necessary to reduce the power consumption Pc or keep constant the same. Such linear control of the overcurrent limit value Iocd is specifically described below with reference to the drawings.

FIG. 8 is a timing chart showing linear control of the reference current IREF (therefore the overcurrent limit value Iocd of the output current Io), in which the power supply voltage VBB, the lower side current IL, and the reference current IREF ( $= I_H - I_L$ ) are shown in order from top to bottom. As an assumption of this chart, it is supposed that an output short circuit of the load 3 and an overcurrent abnormality of the output current Io are both detected in the semiconductor integrated circuit device 1 ( $S_A = S_B = H$  in FIG. 5 or 6).

The power supply voltage VBB is maintained at the normal value Vnormal ( $< V_{TH}$ ) until time t1. Therefore, the lower side current IL is zero so that the reference current IREF is equal to the upper side current IH. Note that  $I_L = 0$  holds because the differential amplified voltage V2 is zero when  $V_{BB} < V_{TH}$  holds. In addition, if the lower side current control unit 114 adopts the second structural example (FIG. 6) described above, even if the differential amplified voltage V2 is raised from zero because of a certain cause, the lower side current IL is fixed to zero. This point is already described above.

At the time t1, the power supply voltage VBB starts to increase from the normal value Vnormal. However, from the time t1 to time t2,  $V_{BB} < V_{TH}$  still holds, and hence the lower side current IL is maintained at zero similarly to before the time t1. Therefore, the reference current IREF is not decreased and is maintained at the same value as the upper side current IH.

At the time t2, when the power supply voltage VBB becomes higher than the threshold value voltage VTH, the lower side current IL starts to flow, thereby the reference current IREF is decreased. Note that the lower side current IL increases higher as the power supply voltage VBB is higher. Therefore, the reference current IREF decreases along with an increase in the power supply voltage VBB.

When the power supply voltage VBB changes from increase to decrease at time t3, the lower side current IL starts to decrease, and hence the reference current IREF changes from decrease to increase. However, from the time



## 13

t3 to time t4,  $V_{BB} > V_{TH}$  still holds, and hence the lower side current  $I_L$  continues to flow. As a result, the reference current  $I_{REF}$  is still decreased corresponding to the lower side current  $I_L$ .

When the power supply voltage  $V_{BB}$  becomes lower than the threshold value voltage  $V_{TH}$  at the time t4, the lower side current  $I_L$  does not flow. Therefore, the reference current  $I_{REF}$  is not decreased any more and returns to the same value as the upper side current  $I_H$ .

After time t5, the power supply voltage  $V_{BB}$  is maintained at the normal value  $V_{normal}$  ( $< V_{TH}$ ) again. Therefore, the lower side current  $I_L$  does not flow, and the reference current  $I_{REF}$  is maintained at the upper side current  $I_H$ .

As described above, in the overcurrent protection circuit 71, when an output short circuit of the load 3 is detected ( $S_A = H$ ), and when an abnormality of overcurrent of the output current  $I_o$  is detected ( $S_B = H$ ), only in the case where the power supply voltage  $V_{BB}$  is higher than the predetermined threshold value voltage  $V_{TH}$ , the reference current  $I_{REF}$  (therefore the overcurrent limit value  $I_{ocd}$  of the output current  $I_o$ ) is linearly decreased according to a difference value between the power supply voltage  $V_{BB}$  and the threshold value voltage  $V_{TH}$  (i.e.  $V_{BB} - V_{TH}$ ).

FIG. 9 is a correlation diagram between the power supply voltage  $V_{BB}$  and the overcurrent limit value  $I_{ocd}$  as well as the power consumption  $P_c$ . As shown in this diagram, in the overcurrent protection circuit 71, it is preferred to decrease the overcurrent limit value  $I_{ocd}$  of the output current  $I_o$ , so that the power consumption  $P_c$  in the NMOSFET 10 becomes constant in a voltage range of the power supply voltage  $V_B$  higher than the predetermined threshold value voltage  $V_{TH}$  ( $V_{normal} < V_{TH} < V_{BB} < V_{max}$ ).

As described above, in the overcurrent protection circuit 71 having the linear control function of the overcurrent limit value  $I_{ocd}$ , when an output short circuit of the load 3 (and an overcurrent abnormality of the output current  $I_o$  due to the same) is generated, even if an overvoltage abnormality of the power supply voltage  $V_{BB}$  further occurs, the power consumption  $P_c$  of the NMOSFET 10 can be reduced or kept constant by appropriately decreasing the overcurrent limit value  $I_{ocd}$  of the output current  $I_o$ .

In a switch device like the semiconductor integrated circuit device 1 proposed above, in a low on-resistance range (e.g. a few  $m\Omega$  to a few tens of  $m\Omega$ ) in which relatively large output current flows, or in a switch device for in-vehicle use that is not allowed to be destroyed in any case, it is very effective to have the linear control function of the overcurrent limit value  $I_{ocd}$  described above as one measure against an output short circuit.

<Gate Control Unit (Second Structural Example)>

FIG. 10 is a block diagram illustrating a second structural example of the gate control unit 30 and its periphery. The gate control unit 30 of this structural example includes the gate driver 31, the oscillator 32, the charge pump 33, the damper 34, NMOSFETs 35a and 35b, the resistor 36 (having a resistance of  $R_{36}$ ), and the capacitor 37 (having a capacitance of  $C_{37}$ ).

The gate driver 31 is connected between an output terminal of the charge pump 33 (i.e. an application terminal of the stepped-up voltage  $V_G$ ) and the external terminal T2 (i.e. the application terminal of the output voltage  $V_o$ ), so as to generate the gate drive signal  $G_1$  whose current capacity is increased from that of the gate control signal  $S_1$ . Note that the gate drive signal  $G_1$  is basically becomes high level (i.e.

## 14

$V_G$ ) when the gate control signal  $S_1$  is at high level, and becomes low level (i.e.  $V_o$ ) when the gate control signal  $S_1$  is at low level.

The oscillator 32 generates the clock signal  $CLK$  having a predetermined frequency and outputs it to the charge pump 33. Note that the oscillator 32 is enabled or disabled according to the enable signal  $S_a$  from the control logic portion 40.

The charge pump 33 drives the flying capacitor (not shown) using the clock signal  $CLK$  so as to generate the stepped-up voltage  $V_G$  higher than the power supply voltage  $V_{BB}$ . Note that the charge pump 33 is enabled or disabled according to the enable signal  $S_b$  from the control logic portion 40.

The clamper 34 is connected between the external terminal T1 (i.e. the application terminal of the power supply voltage  $V_{BB}$ ) and the gate of the NMOSFET 10. In an application in which the inductive load 3 is connected to the external terminal T2, when the NMOSFET 10 is switched from on to off, a counter electromotive force of the load 3 makes the output voltage  $V_o$  become a negative voltage ( $< GND$ ). For this reason, the damper 34 (so-called active clamp circuit) is disposed for absorption of energy.

The drain of the NMOSFET 35a is connected to the gate of the NMOSFET 10. The source of the NMOSFET 35a is connected to the external terminal T2. Note that the gate of the NMOSFET 35a is applied with a first overcurrent protection signal  $S_{71a}$  (corresponding to the overcurrent protection signal  $S_{71}$  described above) from the overcurrent protection circuit 71. In addition, the resistor 36 and the capacitor 37 are connected in series between the drain and gate of the NMOSFET 35a.

The drain of the NMOSFET 35b is connected to the gate of the NMOSFET 10. The source of the NMOSFET 35b is connected to the external terminal T2. The gate of the NMOSFET 35b is applied with a second overcurrent protection signal  $S_{71b}$  from the overcurrent protection circuit 71. However, neither a resistor nor a capacitor is connected between the drain and gate of the NMOSFET 35b unlike the NMOSFET 35a.

In the gate control unit 30 of this structural example, the NMOSFET 35a is turned off when the first overcurrent protection signal  $S_{71a}$  is at low level (i.e. a logic level when no abnormality is detected), and is turned on when the first overcurrent protection signal  $S_{71a}$  is at high level (i.e. a logic level when an abnormality is detected). Therefore, when the first overcurrent protection signal  $S_{71a}$  is raised to high level, the gate drive signal  $G_1$  is decreased from high level (i.e.  $V_G$ ) in the normal state with the predetermined time constant  $\tau (= R_{36} \times C_{37})$ . As a result, the conduction degree of the NMOSFET 10 is gradually decreased, so that the output current  $I_o$  is limited. In contrast, when the first overcurrent protection signal  $S_{71a}$  is decreased to low level, the gate drive signal  $G_1$  is increased with the predetermined time constant  $\tau$ . As a result, the conduction degree of the NMOSFET 10 is gradually increased, and hence limitation of the output current  $I_o$  is cancelled.

In addition, the NMOSFET 35b is turned off when the second overcurrent protection signal  $S_{71b}$  is at low level (i.e. a logic level when the forced turn-off is cancelled), and is turned on when the second overcurrent protection signal  $S_{71b}$  is at high level (i.e. a logic level in the forced turn-off). Therefore, when the second overcurrent protection signal  $S_{71b}$  is raised to high level, the gate and source of the NMOSFET 10 are short-circuited, so that the NMOSFET 10 is forcibly turned off, and the output current  $I_o$  is cut off without delay. In contrast, when the second overcurrent protection signal  $S_{71b}$  is decreased to low level, the gate and



## 15

source of the NMOSFET 10 are disconnected, and hence the forced turn-off of the NMOSFET 10 is cancelled.

<Current Protection Circuit (First Embodiment)>

FIG. 11 is a block diagram illustrating a first embodiment of the overcurrent protection circuit 71. The overcurrent protection circuit 71 of this embodiment includes a current control unit 210 and a duty control unit 220.

The current control unit 210 compares the sense voltage  $V_s$  (corresponding to the output current  $I_o$ ) with the predetermined threshold value voltage  $V_{th}$  (corresponding to the upper limit value  $I_{ocd}$  of the output current  $I_o$ , not shown in this diagram), so as to generate the first overcurrent protection signal  $S71a$  to control the conduction degree of the NMOSFET 10. In addition, the current control unit 210 also has a function of generating a status notification signal  $S210$  for notifying the duty control unit 220 that the current control unit 210 limits the output current  $I_o$  ( $S71a=H$ ) based on a result of the comparison described above.

The duty control unit 220 is an example of an intermittent control unit that intermittently drives the NMOSFET 10 when an overcurrent is detected, and receives the status notification signal  $S210$  so as to generate the second overcurrent protection signal  $S71b$ . More specifically, when the current limiting operation of the current control unit 210 ( $S71a=H$ ) continues for a predetermined on period  $T_{on}$ , the duty control unit 220 generates the second overcurrent protection signal  $S71b$  so that the NMOSFET 10 is turned off for a predetermined off period  $T_{off}$ .

<Current Control Unit>

FIG. 12 is a circuit diagram illustrating a structural example of the current control unit 210. The current control unit 210 of this structural example includes a current source 211, a resistor 212 (having a resistance of  $R_{ref}$ ), a comparator 213, an NMOSFET 214, PMOSFETs 215 and 216, a depletion type NMOSFET 217, and a zener diode 218.

A first terminal of the current source 211 and a power supply potential terminal of the comparator 213 are both connected to an application terminal of the stepped-up voltage  $V_G$ . A second terminal of the current source 211 and a first terminal of the resistor 212 are both connected to an inverting input terminal (-) of the comparator 213. A non-inverting input terminal (+) of the comparator 213 is applied with the sense voltage  $V_s$ . A second terminal of the resistor 212 and a reference potential terminal of the comparator 213 are both connected to the application terminal of the output voltage  $V_o$ . An output terminal of the comparator 213 corresponds to an output terminal of the first overcurrent protection signal  $S71a$ .

The gate of the NMOSFET 214 is connected to an output terminal of the comparator 213. The source of the NMOSFET 214 is connected to the application terminal of the output voltage  $V_o$ . The drain of the NMOSFET 214 is connected to the drain of the PMOSFET 215. The sources of the PMOSFETs 215 and 216 are both connected to the application terminal of the stepped-up voltage  $V_G$ . The gates of the PMOSFETs 215 and 216 are both connected to the drain of the PMOSFET 215. The drain of the PMOSFET 216 is connected to the drain of the NMOSFET 217 and the cathode of the zener diode 218. The gate and source of the NMOSFET 217 and the anode of the zener diode 218 are both connected to the ground terminal GND. Note that the drain of the PMOSFET 216 corresponds to an output terminal of the status notification signal  $S210$ .

The current source 211 generates a predetermined reference current  $I_{ref}$  and supplies it to the resistor 212. Therefore, the inverting input terminal (-) of the comparator 213 is applied with the predetermined threshold value voltage

## 16

$V_{th} (=I_{ref} \times R_{ref})$ . Note that a voltage value of the threshold value voltage  $V_{th}$  is set appropriately according to the upper limit value  $I_{ocd}$  of the output current  $I_o$ .

The comparator 213 compares the sense voltage  $V_s$  input to the non-inverting input terminal (+) with the threshold value voltage  $V_{th}$  input to the inverting input terminal (-), so as to generate the first overcurrent protection signal  $S71a$ . The first overcurrent protection signal  $S71a$  becomes low level (i.e. a logic level when no abnormality is detected) when the sense voltage  $V_s$  is lower than the threshold value voltage  $V_{th}$ , and becomes high level (i.e. a logic level when an abnormality is detected) when the sense voltage  $V_s$  is higher than the threshold value voltage  $V_{th}$ .

The NMOSFET 214 becomes turned off when the first overcurrent protection signal  $S71a$  is at low level, and becomes turned on when the first overcurrent protection signal  $S71a$  is at high level. The PMOSFETs 215 and 216 form a current mirror, which mirrors a drain current  $I_{d1}$  of the PMOSFET 215 so as to generate a drain current  $I_{d2}$  of the PMOSFET 216. The depletion type NMOSFET 217 functions as a constant current source because the gate and source thereof are connected to each other. The zener diode 218 functions as a clamp element that limits the upper limit value of the status notification signal  $S210$ .

In the current control unit 210 of this structural example, when the first overcurrent protection signal  $S71a$  is at low level, the NMOSFET 214 is turned off, and hence a current path from the drain of the PMOSFET 215 to the application terminal of the output voltage  $V_o$  is disconnected. Therefore, the drain currents  $I_{d1}$  and  $I_{d2}$  do not flow, and the status notification signal  $S210$  becomes low level (i.e. a logic level when the limitation of the output current  $I_o$  is cancelled).

On the contrary, when the first overcurrent protection signal  $S71a$  is at high level, the NMOSFET 214 is turned on, and hence the current path described above is connected. Therefore, the drain currents  $I_{d1}$  and  $I_{d2}$  flow, and the status notification signal  $S210$  is at high level (i.e. a logic level when the output current  $I_o$  is limited).

FIG. 13 is a circuit diagram illustrating a variation of the current control unit 210. The current control unit 210 of this variation is based on the circuit structure of FIG. 12 and includes NMOSFETs 213a and 213b and a current source 213c as circuit elements that substitute the comparator 213.

The first terminals of the current sources 211 and 213c are both connected to the application terminal of the stepped-up voltage  $V_G$ . The second terminal of the current source 211 is connected to the drain of the NMOSFET 213a. A second terminal of the current source 213c is connected to the drain of the NMOSFET 213b. The source of the NMOSFET 213a is connected to the first terminal of the resistor 212. The second terminal of the resistor 212 is connected to the application terminal of the output voltage  $V_o$ . The gates of the NMOSFET 213a and the NMOSFET 213b are both connected to the drain of the NMOSFET 213a. The source of the NMOSFET 213b is applied with the sense voltage  $V_s$ . Note that the drain of the NMOSFET 213b corresponds to the output terminal of the first overcurrent protection signal  $S71a$ .

In this way, in the current control unit 210, it may be possible to adopt a comparison circuit using a current mirror as a circuit element that substitutes the comparator 213 in FIG. 12.

<Current Protection Operation>

FIG. 14 is a timing chart showing an example of an overcurrent protection operation, in which the output current



$I_o$ , the first overcurrent protection signal  $S71a$ , and the second overcurrent protection signal  $S71b$  are shown in order from top to bottom.

Before the time  $t1$ , the NMOSFET **10** is turned on so that the predetermined output current  $I_o$  flows. In this case, if  $I_o < I_{ocd}$  holds, the first overcurrent protection signal  $S71a$  and the second overcurrent protection signal  $S71b$  are both at low level, and hence the overcurrent protection operation is not performed.

If an output short circuit of the load **3** (i.e. a short circuit to ground from the external terminal  $T2$ ) or the like occurs at the time  $t1$  so that the output current  $I_o$  is increased to the upper limit value  $I_{ocd}$ , the first overcurrent protection signal  $S71a$  is raised to high level. As a result, the output current  $I_o$  is limited to the upper limit value  $I_{ocd}$  or less. Further in this case, the duty control unit **220** starts to count the predetermined on period  $T_{on}$  (e.g. a few  $\mu$ sec to a few tens of  $\mu$ sec). Note that the second overcurrent protection signal  $S71b$  is maintained at low level until the count operation of the on period  $T_{on}$  is completed. Therefore, the NMOSFET **10** is not forcibly turned off.

When the count operation of the on period  $T_{on}$  is completed at the time  $t2$  with the overcurrent limiting operation performed ( $S71a=H$ ) by the current control unit **210**, the second overcurrent protection signal  $S71b$  is raised to high level. As a result, the MOSFET **10** is forcibly turned off so that the output current  $I_o$  does not flow, and hence the first overcurrent protection signal  $S71a$  is decreased to low level. Further in this case, the duty control unit **220** starts to count the predetermined off period  $T_{off}$  (e.g. a few hundreds of  $\mu$ sec). Note that the second overcurrent protection signal  $S71b$  is maintained at high level until the count operation of the off time  $T_{off}$  is completed.

When the count operation of the off time  $T_{off}$  is completed at the time  $t3$ , the second overcurrent protection signal  $S71b$  is decreased to low level. As a result, the forced turn-off of the MOSFET **10** is cancelled, and hence the output current  $I_o$  starts to flow again. In this case, if the output short circuit of the semiconductor integrated circuit device **1** is not cancelled, the output current  $I_o$  is raised again to the upper limit value  $I_{ocd}$ . As a result, also after the time  $t3$ , the overcurrent protection operation similar to the above description is repeated.

In other words, after the time  $t1$ , the NMOSFET **10** alternately repeats the on period  $T_{on}$  and the off period  $T_{off}$  with a predetermined duty ratio  $Don$  ( $=T_{on}/T$ , where  $T=T_{on}+T_{off}$ ).

Note that the duty ratio  $Don$  should be appropriately set so that junction temperature  $T_j$  of the semiconductor integrated circuit device **1** (particularly inside or in a vicinity of the NMOSFET **10**) is securely decreased to a safe temperature range. For instance, the junction temperature  $T_j$  is not maintained in a high temperature range (150 to 175 degrees Celsius) after the time  $t1$  if  $Don$  is set to approximately 4%, and it can be decreased to a sufficiently safe temperature range (approximately 70 to 80 degrees Celsius). Thus, safety of the semiconductor integrated circuit device **1** can be enhanced.

In this way, as an overcurrent protection method in the overcurrent protection circuit **71** of the first embodiment, a method of limiting the output current  $I_o$  to the upper limit value  $I_{ocd}$  or less without turning off the same (a so-called current limit method) and a method of intermittently turning on and off the output current  $I_o$  with a predetermined duty ratio  $Don$  (a so-called duty control method) are combined.

In particular, the duty control method described above can be said to be a very effective control method to clear a

reliability test unique to in-vehicle devices (e.g. a load short-circuit reliability test (such as automotive electronics council (AEC) Q100-012) to evaluate safety in a short circuit to power supply voltage or to ground from the output terminal).

However, the duty control method described above has bad compatibility with a capacitive load. This drawback is considered below.

<Start-Up Delay Occurrence>

FIG. **15** is a timing chart showing a manner in which startup delay occurs due to the duty control, in which the external control signal  $S1$ , the output voltage  $V_o$ , and the output current  $I_o$  are shown in order from top to bottom.

When the external control signal  $S_i$  is raised to high level at time  $t11$ , the NMOSFET **10** is turned on so that the output current  $I_o$  starts to flow. In this case, if a capacitive load such as a bulb lamp is connected as the load **3**, or if an external capacitor is connected in parallel to the load **3**, the output current  $I_o$  larger than the upper limit value  $I_{ocd}$  (i.e. inrush current) transiently flows until sufficient charge is stored in the capacitance. Therefore, the output current  $I_o$  is limited to the predetermined upper limit value  $I_{ocd}$  or less by the overcurrent protection operation of the current limit method.

In addition, when the on period  $T_{on}$  from the time  $t11$  elapses at time  $t12$ , the NMOSFET **10** is forcibly turned off by the overcurrent protection operation of the duty control method. Therefore, the output current  $I_o$  cannot flow into the capacitive load or the external capacitor connected to the external terminal  $T2$ , and hence the increase in the output voltage  $V_o$  (i.e. charging of the capacitance) is stopped.

Therefore, if the output voltage  $V_o$  does not reach a target value  $V_{target}$  (approximately  $V_{BB}$ ) before the overcurrent protection operation by the duty control method is performed, the output voltage  $V_o$  is raised step by step. As a result, startup time of the output voltage  $V_o$  is increased.

Note that in this chart, the NMOSFET **10** is turned on again at time  $t13$ , and consequently the output voltage  $V_o$  reaches the target value  $V_{target}$  (approximately  $V_{BB}$ ). In other words, the output voltage  $V_o$  is raised in two steps. However, the number of startup steps of the output voltage  $V_o$  may be further increased depending on a capacitance of the load **3** or a voltage value of the power supply voltage  $V_{BB}$ , and a startup failure may occur depending on a set.

Further, if the duty control unit **220** is simply eliminated in order to cancel the startup delay or the startup failure described above, the forced turn-off control of the NMOSFET **10** is charged on the temperature protection circuit **73**. As a result, when an output short circuit of the load **3** occurs, the NMOSFET **10** continues to turn on and off in the high temperature range (e.g. 150 to 175 degrees Celsius) in which detection and cancellation of the temperature abnormality due to the overcurrent are repeated, and hence safety of the semiconductor integrated circuit device **1** is sacrificed.

As means for achieving both stable startup and functional safety of the semiconductor integrated circuit device **1**, a second embodiment of the overcurrent protection circuit **71** is proposed below.

<Current Protection Circuit (Second Embodiment)>

FIG. **16** is a block diagram illustrating the second embodiment of the overcurrent protection circuit **71**. The overcurrent protection circuit **71** of this embodiment is based on the first embodiment (FIG. **11**) described above, and further includes an output voltage monitoring portion **230**. Accordingly, the same structural element as the first embodiment is denoted by the same numeral or symbol as in FIG. **11** so that overlapping description is omitted, and characteristic parts of this embodiment are mainly described below.



The output voltage monitoring portion **230** generates an output voltage monitor signal **S230** so that the duty control unit **220** is disabled until the output voltage  $V_o$  applied to the load **3** becomes its target value  $V_{target}$  (approximately  $V_{BB}$ ). The output voltage monitor signal **S230** is at low level (i.e. a logic level when the duty control is disabled) when  $V_o < V_{target}$  (approximately  $V_{BB}$ ) holds, and is at high level (i.e. a logic level when the duty control is enabled) when  $V_o = V_{target}$  (approximately  $V_{BB}$ ) holds.

<Output Voltage Monitoring Portion>

FIG. **17** is a circuit diagram illustrating a structural example of the output voltage monitoring portion **230**. The output voltage monitoring portion **230** of this structural example includes N-channel MOS field effect transistors **N11** to **N20**, P-channel MOS field effect transistors **P11** and **P12**, and zener diodes **ZD1** to **ZD3**. Note that the transistors **N11** to **N13** are all enhancement types, and the transistors **N14** to **N20** are all depletion types.

The drain of the transistor **N15** is connected to an application terminal of an internal voltage  $V_{BBREF}$  (approximately  $V_{BB}$ ). The source and gate of the transistor **N15** are connected to the drains of the transistors **N11** and **N14** and the cathode of the zener diode **ZD1**. The gates of the transistors **N11** and **N12** are both connected to the drain of the transistor **N11**. The sources of the transistors **N11** and **N12**, the source and gate of the transistor **N14**, and the anode of the zener diode **ZD1** are all connected to the application terminal of the output voltage  $V_o$  (i.e. the external terminal **T2**). Note that the transistors **N11** and **N12** connected in this way function as a current mirror **CM**.

The drains of the transistors **N16** to **N18** and the cathode of the zener diode **ZD2** are all connected to the application terminal of the power supply voltage  $V_{BB}$  (i.e. the external terminal **T1**). The source and gate of the transistor **N16**, the anode of a zener diode **ZD2**, and the gate of the transistor **P11** are all connected to the drain of the transistor **N12**. The source and gate of the transistor **N17** are connected to the source of the transistor **P11**. The source and gate of the transistor **N18** are connected to the source of the transistor **P12**.

The drain of the transistor **P11** is connected to the gate of the transistor **P12** and the drain of the transistor **N13**. The source of the transistor **N13** is connected to the drain of the transistor **N19**. The gate of the transistor **N13** is connected to an input terminal of the enable signal **EN**. The source and gate of the transistor **N19** are connected to an application terminal of the internal voltage  $V_{BBM5}$  (approximately  $V_{BB}-5\text{ V}$ ). As the transistor **P11** that works between  $V_{BB}$  and  $V_{BBM5}$ , a low withstand voltage element (e.g. a withstand voltage of a few volts) can be used.

The drain of the transistor **P12** is connected to the drain of the transistor **N20**, the cathode of the zener diode **ZD3**, and an output terminal of the output voltage monitor signal **S230**. The source and gate of the transistor **N20** and the anode of the zener diode **ZD3** are all connected to the ground terminal. As the transistor **P12** that works between  $V_{BB}$  and  $GND$ , it is necessary to use a high withstand voltage element (e.g. a withstand voltage of a few tens of volts).

Next, an operation of output voltage monitoring portion **230** is described. When the external control signal  $S_i$  is raised to high level so that the NMOSFET **10** is turned on, the output voltage  $V_o$  starts to rise from 0 V at a predetermined slew rate. In this case, just after the NMOSFET **10** is turned on, a potential difference larger than an on threshold voltage of each of the transistors **N11** and **N12** is generated between  $V_{BBREF}$  and  $V_o$ . Therefore, the current mirror **CM** is enabled so that a mirror current  $I_m$  flows in the drain of

the transistor **N12**. Consequently, a gate voltage  $V_{11}$  of the transistor **P11** becomes low level (substantially the output voltage  $V_o$ ). As a result, the transistor **P11** is turned on, and a gate voltage  $V_{12}$  of the transistor **P12** becomes high level (substantially the power supply voltage  $V_{BB}$ ), so that the transistor **P12** is turned off, and the output voltage monitor signal **S230** becomes low level (i.e. a logic level when the duty control is disabled).

After that, the potential difference between  $V_{BBREF}$  and  $V_o$  is decreased along with an increase of the output voltage  $V_o$ . When the output voltage  $V_o$  reaches its target value  $V_{target}$  (approximately  $V_{BB}$ ), the potential difference between  $V_{BBREF}$  and  $V_o$  becomes less than the on threshold voltages of the transistors **N11** and **N12**. Therefore the current mirror **CM** is disabled so that the mirror current  $I_m$  does not flow in the drain of the transistor **N12**, and hence the gate voltage  $V_{11}$  of the transistor **P11** becomes high level (substantially the power supply voltage  $V_{BB}$ ). As a result, the transistor **P11** is turned off, and the gate voltage  $V_{12}$  of the transistor **P12** becomes low level (substantially the internal voltage  $V_{BBM5}$ ), so that the transistor **P12** is turned off. Consequently, the output voltage monitor signal **S230** becomes high level (i.e. a logic level when the duty control is enabled).

In this way, the output voltage monitoring portion **230** of this structural example can detect whether or not the output voltage  $V_o$  has reached the target value  $V_{target}$  (approximately  $V_{BB}$ ) with a very simple circuit structure.

Note that the transistor **N13** is turned on when the enable signal **EN** is at high level and is turned off when the enable signal **EN** is at low level. Therefore, the output voltage monitoring portion **230** is enabled or disabled according to the enable signal **EN**. As the enable signal **EN**, it is possible to use the external control signal  $S_i$  transmitted from the external terminal **T3** via the signal input portion **50**.

<Cancellation of Startup Delay>

FIG. **18** is a timing chart showing a manner in which the startup delay is cancelled by introducing the output voltage monitoring portion **230**, in which the external control signal **S1**, the output voltage  $V_o$ , the output voltage monitor signal **S230**, and the output current  $I_o$  are shown in order from top to bottom. Note that solid lines in this chart indicate behaviors in the second embodiment (with the output voltage monitor), while broken lines in this chart indicate behaviors in the first embodiment (without the output voltage monitor).

When the external control signal  $S_i$  is raised to high level at time  $t_{21}$ , the NMOSFET **10** is turned on so that the output current  $I_o$  starts to flow. In this case, if a capacitive load such as a bulb lamp is connected as the load **3**, or if an external capacitor is connected in parallel to the load **3**, the output current  $I_o$  larger than the upper limit value  $I_{ocd}$  (i.e. inrush current) transiently flows until sufficient charge is stored in the capacitance. Therefore, the output current  $I_o$  is limited to the predetermined upper limit value  $I_{ocd}$  or less by the overcurrent protection operation of the current limit method. This point is the same as already described above with reference to FIG. **15**.

In contrast, the operation of the duty control unit **220** is disabled by the output voltage monitor signal **S230** maintained at low level until the output voltage  $V_o$  reaches its target value  $V_{target}$  (approximately  $V_{BB}$ ). Therefore, when the on period  $T_{on}$  elapses from the time  $t_{21}$ , the NMOSFET **10** is not forcibly turned off, and the overcurrent protection operation of the current limit method is continued. Therefore, the output current  $I_o$  can continuously flow to the capacitive load or the external capacitor connected to the



## 21

external terminal T2, so that the output voltage Vo can rise without delay, and hence the startup time of the output voltage Vo can be reduced.

After that, when the output voltage Vo reaches its target value Vtarget (approximately VBB) at time t22 so that the output voltage monitor signal S230 is raised to high level, the duty control unit 220 is enabled. As a result, after the time t22, if an overcurrent abnormality of the output current Io due to an output short circuit of the load 3 occurs, the overcurrent protection operation of the duty control method described above is enabled. Therefore, the junction temperature Tj of the semiconductor integrated circuit device 1 is not maintained in the high temperature range (150 to 175 degrees Celsius), and it can be decreased to the sufficiently safe temperature range (approximately 70 to 80 degrees Celsius) so that safety of the semiconductor integrated circuit device 1 can be enhanced.

As described above, in the overcurrent protection circuit 71 of the second embodiment, the duty control unit 220 is disabled so that the overcurrent protection operation of the current limit method is continued until the output voltage Vo is sufficiently raised after the NMOSFET 10 is turned on, and the duty control unit 220 is enabled after the output voltage Vo is sufficiently raised.

According to this overcurrent protection operation, compatibility between stable startup and functional safety of the semiconductor integrated circuit device 1 can be achieved, and hence various specifications of the load 3 can be flexibly supported, while functional safety required to the semiconductor integrated circuit device 1 can be cleared at high level.

In the above description, the output voltage monitor signal S230 is used as a the control signal for switching the duty control unit 220 between enabled and disabled in the overcurrent protection circuit 71. However, if there is any other abnormality protecting portion than the duty control unit 220 that can inhibit the output voltage Vo from rising, it is possible to use the output voltage monitor signal S230 as a control signal for switching the abnormality protecting portion between enabled and disabled. An application to the temperature protection circuit 73 is exemplified and described briefly below.

<Application to Temperature Protection Circuit>

FIG. 19 is a block diagram illustrating a structural example of the temperature protection circuit 73. The temperature protection circuit 73 of this structural example includes a first temperature detection portion 73A, a second temperature detection portion 73B, and a logical OR operator 73C.

The first temperature detection portion 73A (corresponding to the overheat protection portion) detects junction temperature Tj1 of the NMOSFET 10 using a temperature detection element D1 disposed inside or in a vicinity of the NMOSFET 10, and compares the detected value with a predetermined abnormality detection value (e.g. 175 degrees Celsius) as well as an abnormality cancellation value (e.g. 150 degrees Celsius), so as to generate a first temperature protection signal S73A. The first temperature protection signal S73A becomes high level (i.e. a logic level when an abnormality is detected) when the junction temperature Tj1 becomes higher than the abnormality detection value, and becomes low level (i.e. a logic level when no abnormality is detected) when the junction temperature Tj1 becomes lower than the abnormality cancellation value.

The second temperature detection portion 73B (corresponding to the temperature difference protection portion) detects junction temperature Tj2 of an integrated circuit 200

## 22

(such as the control logic portion 40) except the NMOSFET 10 using a temperature detection element D2 disposed inside or in a vicinity of the integrated circuit 200. The second temperature detection portion 73B compares a temperature difference  $\Delta Tj (=Tj1-Tj2)$  between the junction temperature Tj1 and the junction temperature Tj2 with a predetermined abnormality detection value (e.g. 60 degrees Celsius) as well as an abnormality cancellation value (e.g. 45 degrees Celsius), so as to generate a second temperature protection signal S73B. The second temperature protection signal S73B becomes high level (i.e. a logic level when an abnormality is detected) when the temperature difference  $\Delta Tj$  becomes more than the abnormality detection value and becomes low level (i.e. a logic level when no abnormality is detected) when the temperature difference  $\Delta Tj$  becomes less than the abnormality cancellation value.

The logical OR operator 73C performs a logical OR operation between the first temperature protection signal S73A and the second temperature protection signal S73B so as to generate a third temperature protection signal S73C. The third temperature protection signal S73C becomes low level when the first temperature protection signal S73A and the second temperature protection signal S73B are both at low level, and becomes high level when at least one of the first temperature protection signal S73A and the second temperature protection signal S73B is at high level. The third temperature protection signal S73C is output to the control logic portion 40 (or the gate control unit 30) instead of the temperature protection signal S73 (see FIG. 1) described above.

The temperature protection circuit 73 having the structure described above performs self-reset type temperature protection operation, in which the NMOSFET 10 is forcibly turned off when the junction temperature Tj1 or the temperature difference  $\Delta Tj$  becomes higher than the corresponding abnormality detection value, and the forced turn-off of the NMOSFET 10 is cancelled when the junction temperature Tj1 or the temperature difference  $\Delta Tj$  becomes lower than the corresponding abnormality cancellation value.

Similarly to the duty control unit 220 described above, the second temperature detection portion 73B corresponds to the intermittent control unit that intermittently drives the NMOSFET 10 when an abnormality is detected, and it is switched between enabled and disabled according to the output voltage monitor signal S230. More specifically, the second temperature detection portion 73B is disabled when S230 is at low level (i.e. when  $Vo < Vtarget$  (approximately VBB) holds), and is enabled when S230 is at high level (i.e. when  $Vo = Vtarget$  (approximately VBB) holds).

Therefore, after the NMOSFET 10 is turned on, even if the temperature difference  $\Delta Tj$  becomes more than the abnormality detection value when the output voltage Vo has not reached the target value Vtarget (approximately VBB), the second temperature protection signal S73B is not raised to high level, and the NMOSFET 10 is not forcibly turned off. Therefore, the output voltage Vo can be raised without delay, and therefore the startup time of the output voltage Vo can be reduced.

As described above, the output voltage monitor signal S230 can be used also as the control signal for enabling or disabling the second temperature detection portion 73B of the temperature protection circuit 73.

In contrast, the first temperature detection portion 73A is the same as the second temperature detection portion 73B in that it intermittently drives the NMOSFET 10 when an abnormality is detected. However, the first temperature



detection portion 73A does not receive an input of the output voltage monitor signal S230, and the operation thereof is always enabled.

Therefore, when the junction temperature  $T_{j1}$  of the NMOSFET 10 becomes higher than the abnormality detection value, even if the output voltage  $V_o$  has not reached its target value  $V_{target}$  (approximately  $V_{BB}$ ), the NMOSFET 10 is forcibly turned off. This temperature protection operation can protect the NMOSFET 10 from thermal breakdown, and hence safety of the semiconductor integrated circuit device 1 can be enhanced.

<Application to Vehicle>

FIG. 20 is an external view illustrating a structural example of a vehicle. A vehicle X of this structural example is equipped with a battery (not shown in this view), and various electronic apparatuses X11 to X18 that operate with power supply from the battery. Positions of the electronic apparatus X11 to X18 in this view may be different from actual positions for convenience sake of illustration.

The electronic apparatus X11 is an engine control unit that performs control of an engine (such as injection control, electronic throttle control, idling control, oxygen sensor heater control, and automatic cruise control).

The electronic apparatus X12 is a lamp control unit that performs on/off control of a high intensity discharged lamp (HID), a daytime running lamp (DRL), and the like.

The electronic apparatus X13 is a transmission control unit that performs control of a transmission.

The electronic apparatus X14 is a body control unit that performs control of movement of the vehicle X (such as anti-lock brake system (ABS) control, electric power steering (EPS) control, and electronic suspension control).

The electronic apparatus X15 is a security control unit that performs drive control of door lock, anti-theft alarm, and the like.

The electronic apparatus X16 is an electronic apparatus such as a wiper, electric door mirrors, a power window, a damper (shock absorber), an electric sunroof, or an electric sheet, which is mounted in the vehicle X as standard equipment or a manufacturer option when shipped from a factory.

The electronic apparatus X17 is an electronic apparatus such as in-vehicle audio/visual (A/V) equipment, a navigation system, or an electronic toll collection system (ETC), which is mounted in the vehicle X as a user option.

The electronic apparatus X18 is an electronic apparatus such as an in-vehicle blower, an oil pump, a water pump, or a battery cooling fan, which includes a high withstand voltage motor.

The semiconductor integrated circuit device 1, the ECU 2, and the load 3 described above can be incorporated in any of the electronic apparatuses X11 to X18.

<Other Variations>

In addition, in the embodiments described above, an in-vehicle high side switch IC connected between the power supply terminal and the load is exemplified and described, but the application target of the invention disclosed in this specification is not limited to this. For instance, the invention can be widely applied to semiconductor integrated circuit devices other than the in-vehicle use, in addition to other in-vehicle IPD (an in-vehicle low side switch IC connected between the load and the ground terminal, or an in-vehicle power supply IC).

In addition, various technical features disclosed in this specification can be variously modified within the spirit of the technical creation, other than the embodiments described above. In other words, the embodiments described above are

merely examples in every aspect and should not be interpreted as limitations. The technical scope of the present invention is defined not by the above description of the embodiments but by the claims, and should be understood to include all modifications within the meanings and scope equivalent to the claims.

## SUMMARY

Various embodiments disclosed in this specification are summarized below.

The switch device disclosed in this specification has a structure including a switching element arranged to connect/disconnect a current path from a power supply terminal to a ground terminal via a load, and an overcurrent protection circuit arranged to limit output current flowing in the switching element to be an overcurrent limit value or less, in which when an output short circuit of the load is detected, the overcurrent protection circuit decreases the overcurrent limit value to be smaller as a power supply voltage is higher (first structure).

Further, the switch device according to the first structure preferably has a structure in which the overcurrent protection circuit decreases the overcurrent limit value only when the power supply voltage is higher than a predetermined threshold value voltage (second structure).

In addition, the switch device according to the first or second structure preferably has a structure in which the overcurrent protection circuit includes a reference current generation portion arranged to generate a reference current, and a comparison portion arranged to compare a threshold value voltage corresponding to the reference current with a sense voltage corresponding to the output current so as to generate an overcurrent protection signal, and when an output short circuit of the load is detected, the reference current generation portion decreases the reference current to be smaller as the power supply voltage is higher (third structure).

In addition, the switch device according to the third structure preferably has a structure in which the reference current generation portion includes a differential amplifier portion arranged to amplify a difference value between the power supply voltage or its divided voltage and a predetermined reference voltage so as to generate a differential amplified voltage, an upper side current generation portion arranged to generate a predetermined upper side current, a lower side current generation portion arranged to generate a lower side current corresponding to the differential amplified voltage, and a difference current generation portion arranged to output a difference current obtained by subtracting the lower side current from the upper side current, as the reference current (fourth structure).

In addition, the switch device according to the fourth structure preferably has a structure in which the reference current generation portion further includes a lower side current control unit arranged to stop output of the lower side current when at least one of an output short circuit of the load and an overcurrent abnormality of the output current is not detected (fifth structure).

In addition, the switch device according to the fifth structure preferably has a structure in which the lower side current control unit stops output of the lower side current also when an overvoltage abnormality of the power supply voltage is not detected (sixth structure).

In addition, an electronic apparatus disclosed in this specification has a structure including the switch device



25

according to one of the first to sixth structures, and a load connected to the switch device (seventh structure).

The electronic apparatus according to the seventh structure preferably has a structure in which the switch device is a high side switch connected between the power supply terminal and the load, or a low side switch connected between the load and the ground terminal (eighth structure).

In addition, the electronic apparatus according to the seventh or eighth structure preferably has a structure in which the load is one of a bulb lamp, a relay coil, a solenoid, a light emitting diode, and a motor (ninth structure).

In addition, a vehicle disclosed in this specification has a structure including the electronic apparatus according to one of the seventh to ninth structures (tenth structure).

In addition, a switch device disclosed in this specification has a structure including a switching element arranged to connect/disconnect a current path from a power supply terminal to a ground terminal via a load, an intermittent control unit arranged to intermittently drive the switching element when an abnormality is detected, and an output voltage monitoring portion arranged to disable the intermittent control unit until an output voltage applied to the load reaches its target value (eleventh structure).

Further, the switch device according to the eleventh structure preferably has a structure further including a current control unit arranged to limit output current flowing in the switching element to be a predetermined upper limit value or less (twelfth structure).

In addition, the switch device according to the twelfth structure preferably has a structure in which the intermittent control unit includes a duty control unit arranged to turn off the switching element for a predetermined off period when the current limiting operation by the current control unit continues for a predetermined on period (thirteenth structure).

In addition, the switch device according to the thirteenth structure preferably has a structure in which the current control unit compares a sense voltage corresponding to the output current with a threshold value voltage corresponding to the upper limit value, so as to generate a first overcurrent protection signal for controlling a conduction degree of the switching element and a status notification signal for notifying the duty control unit that the current control unit currently limits the output current (fourteenth structure).

In addition, the switch device according to one of the eleventh to fourteenth structures preferably has a structure in which the intermittent control unit includes a temperature difference protection portion arranged to turn off the switching element when a temperature difference between the switching element and other integrated circuits is abnormal (fifteenth structure).

In addition, the switch device according to one of the eleventh to fifteenth structures preferably has a structure further including an overheat protection portion arranged to turn off the switching element when a temperature of the switching element is abnormal even if the output voltage has not reached its target value (sixteenth structure).

In addition, an electronic apparatus disclosed in this specification has a structure including the switch device according to one of the eleventh to sixteenth structures, and a load connected to the switch device (seventeenth structure).

Further, the electronic apparatus according to the seventeenth structure preferably has a structure in which the switch device is a high side switch connected between the

26

power supply terminal and the load, or a low side switch connected between the load and the ground terminal (eighteenth structure).

In addition, the electronic apparatus according to the seventeenth or eighteenth structure preferably has a structure in which the load is one of a bulb lamp, a relay coil, a solenoid, a light emitting diode, and a motor (nineteenth structure).

In addition, a vehicle disclosed in this specification has a structure including the electronic apparatus according to one of the seventeenth to nineteenth structures (twentieth structure).

#### INDUSTRIAL APPLICABILITY

The invention disclosed in this specification can be used for an in-vehicle IPD (such as an in-vehicle switch having high versatility), for example.

What is claimed is:

1. A switch device comprising:

a switching element configured to connect/disconnect a current path from a power supply terminal to a ground terminal via a load;

an overcurrent protection circuit configured to limit output current flowing in the switching element to be an overcurrent limit value or less; and

a duty control unit, wherein

when an output short circuit of the load is detected, the overcurrent protection circuit decreases the overcurrent limit value to be smaller as a power supply voltage is higher,

wherein the overcurrent protection circuit includes:

a reference current generation portion configured to generate a reference current, and

a comparison portion configured to compare a threshold value voltage corresponding to the reference current with a sense voltage corresponding to the output current so as to generate a first overcurrent protection signal for controlling a conduction degree of the switching element, and

when an output short circuit of the load is detected, the reference current generation portion decreases the reference current to be smaller as the power supply voltage is higher, and

wherein the reference current generation portion includes:

a differential amplifier portion,

an upper side current generation portion configured to generate an upper side current,

a lower side current generation portion configured to generate a lower side current, and

a difference current generation portion configured to output a difference current based on the lower side current and the upper side current, as the reference current,

wherein the duty control unit is configured to turn off the switching element for a predetermined off-period when a current limiting operation by the over current protection circuit continues for a predetermined on-period,

wherein the over current protection circuit is configured to generate a status notification signal for notifying the duty control unit that the over current protection circuit currently limits the output current,

wherein the duty control unit is configured to receive the status notification signal so as to generate a second overcurrent protection signal for turning off the switching element for the predetermined off-period when the

27

current limiting operation by the over current protection circuit continues for the predetermined on-period.

2. The switch device according to claim 1, wherein the overcurrent protection circuit decreases the overcurrent limit value only when the power supply voltage is higher than a predetermined threshold value voltage. 5

3. The switch device according to claim 1, wherein the reference current generation portion further includes a lower side current control unit arranged to stop output of the lower side current when at least one of an output short circuit of the load and an overcurrent abnormality of the output current is not detected. 10

4. The switch device according to claim 3, wherein the lower side current control unit stops output of the lower side current also when an overvoltage abnormality of the power supply voltage is not detected. 15

5. An electronic apparatus comprising:  
the switch device according to claim 1, and  
a load connected to the switch device.

6. The electronic apparatus according to claim 5, wherein the switch device is a high side switch connected between

28

the power supply terminal and the load, or a low side switch connected between the load and the ground terminal.

7. The electronic apparatus according to claim 5, wherein the load is one of a bulb lamp, a relay coil, a solenoid, a light emitting diode, and a motor.

8. A vehicle comprising the electronic apparatus according to claim 5.

9. The switch device according to claim 1, wherein the differential amplifier portion is configured to amplify a difference value between the power supply voltage or its divided voltage and a predetermined reference voltage so as to generate a differential amplified voltage.

10. The switch device according to claim 9, wherein the lower side current corresponds to the differential amplified voltage. 15

11. The switch device according to claim 1, wherein the difference current is obtained by subtracting the lower side current from the upper side current.

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